American Heart Journal

VOL. 54 October, 1957 No. 4

Editorial

SELECTION OF MANUSCRIPTS FOR PUBLICATION

THE selection of manuscripts for publication is always a serious matter for the members of the Editorial Board. As will be pointed out below, a number of factors must be taken into consideration. Among these are the character of the subject matter and the manner in which it is handled, supporting evidence, and reasonable discussion and conclusions. Broadly speaking, the subject matter is divisible, in the minds of many, into what they call "clinical" versus "scientific." It is difficult to make a hard and fast distinction between these two concepts. All should be judged as to their influence on the advancement of our knowledge. The term "science" or "scientific" means different things to different people. In other words, what is a science? We have applied science, domestic science, social science, basic medical science, and so on. It may be said that science is really a sincere search for the truth. This may be an oversimplification that would seem to fulfill our present purpose. This now raises a question as to when a clinician becomes a scientist and when a scientist ceases to be a clinician. Perhaps to make this point clearer we might choose at random a few names of men who have been sincere and even tenacious in searching after truth: Harvey, Withering, Bright, and Mackenzie. These are but a few in our own language. They could be added to without number, and if we were to go farther afield the names would be almost infinite. Those mentioned were primarily clinicians and they had, in addition, several qualities in common: keen observation, curiosity, clear thinking, and cautious but imaginative deduction. They were not always right, but they stimulated others to follow in their footsteps. Christopher Columbus and John Cabot were not scientists, but adventurous individuals with imagination, curiosity and tenacity. To draw the line between a clinician and a scientist is impossible. The clinician may light the spark that influences the scientist, and the latter may illuminate the pathway for the former to follow. It is at this point that the exception is often taken that manuscripts are too scientific and not sufficiently practical. This distinction is in itself invalidated if both types are designed to forward our advancement of knowledge and present evidence that this is the case.

And now we come to the subject matter of manuscripts and the reviewer's responsibility in the judgment of manuscripts, with the following points in view: (1) Originality. (2) Whether methodology is adequate or inadequate. (3) Whether the interpretation in the discussion is grossly out of line with the facts presented. The referee can often be helpful in pointing out to the author other interpretations of data which the author should be free

to accept or reject. (4) Whether the referee is a competent critic If the referee does not believe himself to be a competent critic, he does not attempt to evaluate the paper but returns it to the editor whose responsibility it is to balance the opinion of all referees. The manuscript is then either accepted or returned to the author with suggestions as to amendments, which the author is free to take into consideration or to reject. If amendments are made, he may then resubmit his manuscript for final decision by the Editorial Board. If a manuscript is rejected, reasons are usually given. These may include one or more of the following: (1) Not sufficient reader interest; other papers submitted are more pressing in this regard. (2) Not suitable for American Heart Journal publication; better in some other type of journal. (3) Methodology not acceptable. (4) Style too redundant and ill-organized. (5) Results inconsistent, inconclusive, or statistically not valid.

The Editor and his Board have responsibilities to the readers of the Journal which they do not take lightly. They must always bear in mind that their readers cover a diverse field and the contents of the Journal must not be directed to merely one aspect of cardiovascular problems. In fact, the elucidation of normal phenomena may be just as important as the abnormal. Actually, without a basic knowledge of the former, the latter cannot be deduced in true perspective. Furthermore, experimental results on a lower animal may offer the clue to an important process in man although the solution of this should be the ultimate goal. The rapid strides in cardiovascular surgery have opened a vista where man himself may be the experimental animal of first choice.

Then again, there are certain fields which still require clarification either in basic principle or in detail, such as electrocardiography, vectorcardiography, and ballistocardiography. This is particularly true in their relation to man.

There are still many problems in the peripheral circulation which need solution. It must never be forgotten that man is one of the few experimental animals who stand erect, giving rise to hydrostatic problems which are not present in the quadruped.

It is the desire and ambition of the Editorial Board to cater in a measure to all of the Journal's readers whether they be "cardiologists," internists, general practitioners, surgeons, or "scientists." To accomplish this, we are dependent upon the selection of the manuscripts submitted to us. The basic quality of these must be their honesty of purpose to arrive at the truth. This, we appreciate, is often difficult, and sometimes what appears with our concepts of today to be true may prove tomorrow to be false.

Every journal must be appreciative of another difference—the outlook of its readers. Medical teaching and outlook on the cardiovascular system have changed vastly in the past thirty years. We must meet the concepts of the rising generation who will be the leaders of tomorrow. To all, both old and young, we try to carry a message which will help them to understand some of the problems inherent in man and his environment.

This editorial indicates our present policy, and it is our intention to continue along the same lines in the future.

THE EDITOR

Original Communications

EVIDENCE, INCLUDING IN VIVO OBSERVATIONS, SUGGESTING MECHANICAL BLOCKAGE RATHER THAN REFLEX VASOSPASM AS THE CAUSE OF DEATH IN PULMONARY EMBOLIZATION

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INTRODUCTION AND STATEMENT OF THE PROBLEM

THIS investigation was designed to determine whether pulmonary embolization produced reflex constriction in the pulmonary vascular bed. This problem is related to the frequently-heard clinical argument that "One main pulmonary artery can be tied off under surgical anesthesia. In the unanesthetized, embolization of one artery or less can cause death. Reflexes, not damped by anesthesia as they are during surgery, must account for these deaths." Although we have not found good support in the clinical literature for this concept, many attempts have been made to demonstrate such "pulmono-pulmonary reflex vasospasm" in experimental animals. Whether or not such a reflex exists is an important circulatory problem because the pulmonary arteries and arterioles taper rapidly[1,2] and are "in series" with all the rest of the circulation; consequently, they are the most likely resting place, excluding the portal bed, for all potential emboli which enter into or originate in the veins or right heart.

Obstruction of the pulmonary vascular tree causes (1) relative emptiness of systemic arteries, and (2) overdistention of pulmonary arteries, right heart, and systemic veins. These changes in blood distribution induce widespread reflex activity which may be difficult to separate from the postulated intrapulmonary reflex vasospasm. In mammals, experimental approaches are further

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Supported in part by grants from the Duke University Council on Research, the Durham-Orange County Heart Association, and the Life Insurance Medical Research Fund.

Read at the Scientific Sessions of the American Heart Association, Inc., held in Cincinnati, Ohio, October 1956.

Received for publication April 8, 1957.

*Work done during tenure of an American Heart Association Research Fellowship.

**Under tenure of a Life Insurance Medical Research Fund Fellowship.

***Supported by Medical Student Part-time Research Fellowships from U.S.P.H.S.

complicated by the intrathoracic pressure relationships between circulation and respiration; and, opening the thorax before, during, or following embolization may alter the outcome. Nevertheless, we found this approach useful to obtain direct visible evidence about the behavior of pulmonary vessels during pulmonary embolization.

MATERIALS AND METHODS

Some details of materials and methods are included with results. A total of 123 rabbits, 17 cats, and 12 dogs were used. In vivo observations were made in 66 rabbits and 13 cats before, during, and following the intravenous (i.v.) injection of air or of particles from less than 10 to 2,000 microns (μ) in diameter. Where not stated otherwise the emboli were weighed increments of glass beads, 50-150μ, approximately 830,000 per gram. This size range was selected for a majority of the experiments because (1) 50μ is larger than capillaries and 150μ is less than the diameter of the largest visible arteries,[2] and (2) conflicting results have been obtained with this size particle.

To inject a known amount of beads a weighed increment was placed in heparinized saline and drawn up into a syringe through the needle to be used for injection. The beads rapidly settled toward the needle but were injected at a somewhat controllable rate by vertically tilting up the syringe and visibly "feeding" them in with saline. Injections were via an ear vein or cannulated right external jugular, unless otherwise stated.

Quartz rod transillumination[3] and a binocular, bi-objective stereoscopic Leitz dissecting microscope, with magnifications from 16 to 150 times, and a binocular, monobjective microscope with water immersion lenses giving magnifications of 500 and 900 times were used for the in vivo observations. The method for studying lungs has been described.[2] Under surgical anesthesia with veterinary pentobarbital sodium (Abbott), the trachea was cannulated and thorax opened to intercostal muscles. Then, additional barbiturate was given i.v. to a total of 60 mg. per kilogram of body weight (mg./Kg.), intercostals and pleura were cut, and 100 per cent oxygen (O_2) was blown into the lungs via a tube inserted into the tracheal cannula. This O_2 tube did not occlude the cannula; rather, it allowed free escape of gases out of the lungs. With the increased barbiturate and insufflated O_2, the animals respired without movements of the thorax, and thus microscopy of the lungs was possible. The effectiveness of the O_2 insufflation was checked by pulling the O_2 tube out; removal always was followed immediately by respiratory movements. At any one time, only a small portion of lung was externalized and it was bathed by mammalian Ringer's solution at 37.0°C. The quartz rod was carefully maneuvered under the lung and the microscope directed over it. When a desirable field was in focus, the first particle injection was made. Repeatedly, after emboli, movement of the respiratory muscles in response to O_2 removal was checked and failure of such movements was used as an indication of death.

The lethal dose of 50-150μ beads for awake, intact rabbits was first established. Then, the effect on this dose of drugs, surgery, and of making the in vivo pulmonary observations was checked, and microscopic observations were recorded. Later, efforts were made to understand two experimental sources of conflict regarding the existence of reflex pulmonary vasoconstriction: (1) what causes death when particles are infused into one lobe, and (2) what causes death when extremely fine particles are employed as "pulmonary emboli."

RESULTS

The lethal dose of 50-150μ beads for intact, awake rabbits was established using 15 animals. Similar injections were carried out on 15 surgically anesthetized ones, to determine if anesthesia protected against some fatal reflex. Four from each group were given 0.25 Gm./Kg. initially, which proved fatal for all. All others were initially given 0.125 Gm./Kg. and survived this. One each, awake and anesthetized, died from less than 0.20 Gm./Kg., and one awake animal survived a total of 0.25 Gm./Kg. but died from an additional 0.125 Gm./Kg. The remaining 19 died from some total between 0.20 and 0.25 Gm./Kg.

As a specific control for the thoracic surgery of in vivo observed animals, 5 rabbits were anesthetized with pentobarbital 60 mg./Kg., and insufflated with O_2 via a cannula, before being killed with bead emboli. All 5 died from 0.20 to 0.25 Gm./Kg. of beads. In vivo pulmonary observations were made while 30 rabbits were embolized with these 50-150μ beads, and all 30 died from a total between 0.20 and 0.25 Gm./Kg.

In an additional 10 rabbits, the fatal dose of these beads was checked following drugs or vagotomy. One awake rabbit and 2 anesthetized ones were given hexamethonium chloride (C_6) i.v., 5 mg./Kg., and another anesthetized one was given 9 mg./Kg., before the emboli. One awake rabbit was given 0.6 mg./Kg. atropine i.v. before beads, immediately followed by C_6, 5 mg./Kg., and the lung of another was studied in vivo throughout the same procedures. The lungs of 2 rabbits were observed while C_6, 5 mg./Kg., was injected, followed immediately by beads. The lungs of 2 others were studied during faradic stimulation of each intact vagosympathetic trunk, during cutting of each, and during stimulation of both ends of each, followed by fatal bead injection. Neither C_6, atropine, nor any maneuver with the nerves was observed to alter the diameters of any visible pulmonary vessels; and all 10 died from between 0.20 and 0.25 Gm./Kg. of beads.

Anesthesia, thoracotomy, drugs and vagotomy had no apparent effect on the embolic lethal dose of these particles for rabbits. Survival times ranged from 1 minute to 4½ hours, with no group differences. Awake animals convulsed and died in opisthotonos, while anesthetized ones died quietly. At autopsy, the pulmonary veins, left heart, and systemic arteries were virtually bloodless, while systemic veins, liver, right heart, and pulmonary arteries were engorged; and all lungs were collapsed.

Most of the in vivo microscopic observations with these 50-150μ emboli were similar to those made with smaller and larger particles in other animals; therefore, observations common to all are taken up first. All visible effects leading up to and including death could be explained by the mechanical blockage of flow resulting directly from the introduced particles. The diameters and linear flow rates of arteries, capillaries, and veins passively reflected the hemodynamics of their unembolized or embolized parent artery. In nonembolized arteries following nonfatal injections, the pulse slowed for a few beats and there was either no change or increases in their linear flow rates and diameters, followed by a return toward pre-embolic conditions. In embolized vessels and their branches distal to the embolus, as the embolus lodged, the blood either stopped abruptly or slowed markedly; if the embolus did not completely occlude, then blood streamed around it for a short, variable period up to about 5 minutes; and, as the blood flowed past, a white precipitate built up on the particle and completed the blockage. Frequently, nothing more was noted. Sometimes, distal to an embolus, there was a slow reduction in diameter, with variation in both the rate and amount. There was little or no reduction in diameter if collateral flow entered from the arterioles and capillaries which interconnect artery tips.[2] (This observation is relevant in interpreting the observations made with emboli which were too large to enter visible vessels.)

Additional relevant microscopic observations were made. When an animal no longer responded to O_2 withdrawal, the blood in unembolized vessels was always still oscillating, giving evidence that no complete spasm had taken place between the observed vessels and the weakly beating heart. Infrequently, after the introduction of a needle or catheter, but before the injection of particles, masses of white precipitate arrived in pulmonary arteries and embolized them. Sometimes, masses of similar material accompanied particles. Most beads were visibly coated with similar material on arrival in the lung. Frequently, several beads were stuck together by the material and embolized a vessel considerably larger than any single bead. Very frequently an embolus consisted of a line of beads, some of them stuck together. Invariably the precipitate "grew" larger on particles, most rapidly on surfaces against which blood flowed. The "growing" material contained enough red cells to give it color. The proximal growth of precipitate blocked the nearby capillaries and arterioles branching from the artery tip,[1,2,4] and thereby further mechanically blocked flow. Some of the "precipitate" emboli disappeared with time, and flow resumed in these previously embolized vessels. Sometimes all blood distal to an embolus was transformed into a red thrombus.

Observations were made in the lungs of additional animals injected with smaller or larger particles as follows: 10-45μ glass beads in 4 rabbits and 4 cats; Lycopodium spores, 29-32μ, in 2 rabbits and 4 cats; glass beads, 400-450μ in 2 rabbits and 2 cats; and 15, 42, and 51 2,000μ seeds in 3 rabbits. All 3 rabbits survived the seeds, which were introduced one at a time, and were killed with beads. No particle was seen within a pulmonary capillary or vein. Frequently, clumps of the small particles embolized visible arteries. Sometimes, following the injection of one large seed or of small particles, although an embolus did not arrive in the visible surface vessels, an abrupt cessation or reduction of flow in a localized area occurred, and a slow reduction in the diameter of these vessels followed. The reduction in diameter is interpreted as a passive response to reduced hydrostatic pressure caused by separation from the pressure head of the right ventricle by embolization deep within the lung, by a large clump of small particles, or by a single large particle. This interpretation is based upon several additional observations. As stated above, we had seen similar events within visualized arterial segments with 50-150μ beads, when little or no collateral flow entered distal to the embolus. Most collaterals are near the tips,[2] and the bigger an embolus is, the less likely there is to be effective collateral flow. Low-power and gross observations of the surface of the lung showed that these vessels with no flow and reduced diameters were part of a sharply delineated area. The diameters of vessels in surrounding, contiguous areas were unchanged or increased. As more particles were injected, the phenomenon was repeated in other local areas. If this interpretation is correct, it follows that embolization within the lung can cause a reduction in the diameter of surface arteries which could be misinterpreted as being of reflex origin.

In 3 rabbits and 3 cats, fatal pulmonary air bubble embolism was observed. The forward movement of bubbles stopped when the front end reached 40-50μ arterioles. Because bubbles were usually much longer than this diameter, they

blocked most collaterals, the flow usually ceased, and all diameters were reduced distal to the bubble. Bubbles were visibly compressed with each systole, became smaller with time, and were usually absorbed in situ. Seemingly, the bubbles did not leave their site of arrest because the blood precipitated at both ends of the gas. Flow was seldom observed to return following complete gas absorption. A few bubbles passed through the capillaries. These were small on arrival, no precipitate formed on their ends and, when enough gas was absorbed so that they were nearly spheres, they moved forward.

None of the previous experiments gave indication that embolic reflex vasoconstriction occurs; but, because fatal reflex constriction from "localized" embolization had been reported, several experiments were designed to permit this to happen and to gain information about such experiments. Increments of 0.1 Gm. of 50-150μ beads were injected into 3 anesthetized rabbits and 0.5 Gm. into 5 anesthetized dogs, at 2- to 10-minute intervals, via catheters placed in lobar arteries with the aid of a fluoroscope. Injections continued until death. Catheter position was checked and each lobe of each lung was separately hydrolyzed with potassium hydroxide. Beads were recovered from every lobe, approximately twice as many from the catheterized one as from each of the others. One anesthetized and one awake 20-kilogram dog were given 89 and 82 2,000μ seeds, respectively, via catheters in jugular and small saphenous veins. One seed was injected each minute. No fatal reflex occurred and both animals were killed with beads via the catheters. At autopsy, 82 seeds were recovered from the pulmonary arteries of the first, and 61 from the second, and beads were distributed to all lobes in both. Lines of contiguous seeds, 13 in one vessel, were found in both, evidence that no proximal spasm sufficient to inhibit the arrival of the later ones had been initiated by the arrival of the first. Furthermore, the presence of beads in all lobes demonstrated that no complete "lobar" constriction had been initiated prior to their injection. One awake dog was injected via a small saphenous vein on 3 consecutive days with 0.4, 0.8 and 1.6 Gm. of beads without fatality, and 6 weeks later, beads were recovered from all lobes. These experimental conditions permitted these animals to die from "localized" embolization from either size particle, but none did so. Rather, the locally introduced beads were scattered to all lobes before death.

Several experiments were performed to find out (1) if glass beads were per se fatally toxic, and (2) if not, to determine what happened to such emboli and to embolized vessels with the passage of time. In 5 awake and 2 "anesthetized" rabbits (re-anesthetized before each embolization), a total of 0.50 Gm./Kg. of 50-150μ beads was injected in small amounts over a period of months. These rabbits tolerated twice the acutely fatal dose. The lungs were studied in vivo in 3 of these, and in 10 additional rabbits embolized with beads one or more times from 24 hours to 2 months prior to observation. Also, one awake rabbit was injected with Lycopodium spores and studied in vivo 2 weeks later. Extensive precipitate extended proximally and distally from the beads 24 hours after their injection. Within 6 to 8 days after injection, new channels had opened up around the emboli and little precipitate remained. Within 2 weeks, the vasculature and flow rates were nearly normal; however, some vessels "detoured" around previous emboli and almost all particles were "outside" the blood vessels.

Because most beads were coated with a precipitate on their arrival within the lungs and frequently did not behave as discrete entities, observations on the entry and behavior of glass beads in the blood stream were made in 5 rabbits. A midline laparotomy was done and a polyvinyl or polyethylene catheter was threaded into a mesenteric vein, with the tip being placed over the quartz rod. The catheter lumen was visible and, as beads entered the flowing blood, a clear precipitate immediately formed around them. If one entered alone, it was completely coated; if 2 or more entered near each other, not necessarily touching, they were stuck together. Clumps of approximately 50 were formed by allowing a large number to enter the catheter and rapidly squirting them out. Sooner or later a similar precipitate formed about the catheter tip, even though the ends were polished and siliconed. This material took on any shape, from a long streamer to a round "lid." Sometimes pieces broke off. (Pieces of similar material may have been what we had seen within the lung before particles were injected.) Usually all could apparently be blown off by exerting a short forceful pressure on the syringe barrel. Once such material formed, even though all was apparently blown off, a new precipitate rapidly formed at precisely the same location.

Because $BaSO_4$ and starch granules had been reported to cause embolic reflex pulmonary vasoconstriction, the lungs of 2 rabbits were observed while each material was injected i.v. These observations differed from any made previously. The particles arrived in showers in the smallest arterioles and capillaries, and yet the blood continued to flow in most vessels. The linear flow rates never reduced abruptly, even though particles were seen plugging some arterioles and capillaries. After several injections the linear rates gradually reduced, the blood finally was oscillating, and the animals no longer responded to O_2 lack. Although we were not certain that we had seen particles within veins, the possibility of transpulmonary passage was checked. Measurements of particles in a drop of saline showed large numbers smaller than 10μ to be present. Therefore, in one each, heparinized and unheparinized rabbits, cats and dogs, a cannula was placed in the abdominal aorta and, after a control aortic sample, starch or $BaSO_4$ was injected via external jugular and aortic samples collected. The particulate matter was grossly visible in all tubes except those from unheparinized, starch-injected animals, and in these it was visible after centrifugation. The $BaSO_4$ caused gross hemolysis, and at autopsy was found in massive clots in large veins, right heart, and pulmonary arteries of unheparinized animals, and was adherent to the endothelium in small clots in all animals. Particulate matter was grossly visible in the coronary arteries of all animals. These experiments demonstrated that when injected i.v. these materials do not act only as "pulmonary emboli."

DISCUSSION

Direct observation of the lungs during their embolization has helped us understand the course of events. Three points stand out: (1) Small particles can stick together and their injection does not exclude embolization of larger vessels. (2) An intravascular precipitate forms which increases with time and

can further block flow. (3) Very fine particles, such as starch and $BaSO_4$, can pass through the lungs. No experiment yielded any information suggesting the existence of any embolic pulmono-pulmonary vascular reflex. The possibility of making a false positive conclusion by direct observation was noted.

The current acceptance of reflex pulmonary vasoconstriction from small emboli is demonstrated by the following quote from Meakins' *Practice of Medicine*[5]: "Obstruction of smaller vessels is followed by a prompt rise in right ventricular pressure and fall in systemic arterial pressure. Reflexes are set in motion, and there may be widespread pulmonary vascular spasm. . . ." Because this belief is firmly held and is thought to be supported by animal experiments, this literature is discussed. Examination of this literature shows that repeatedly negative results have been obtained with all but very small emboli. Nevertheless, four points have kept alive the belief in such a reflex. First has been the finding of small emboli in branches of the pulmonary artery (PA) at autopsies. This approach has not yielded conclusive results and is only briefly considered at the end of this discussion. Second has been the experimental use of extremely fine particles as emboli. Third has been the infusion of fine particles into a restricted portion of the lung, followed by some generalized response. The last point keeping this belief alive has been the use of either surgery or drugs, such as papaverine, to negate some assumed effects of nerves, and the belief that either of these favorably altered the outcome following embolization. Many negative reports from the literature are taken up first, then works which have yielded supposedly positive results with fine particles and some specific refutations, then experimental data on papaverine's action on pulmonary vessels, and lastly, a specific point relevant to using particles as pulmonary emboli. Many other reflexes have been postulated to arise from pulmonary vessels upon their embolization and to cause changes in heart rate, coronary vasoconstriction, depression of systemic pressure, bronchial constriction and/or secretion, and numerous pneumodynamic responses. These are discussed in recent review articles.[6,7] Only reports directly related to pulmono-pulmonary reflex vasoconstriction are included.

In 1914, Schumacher and Jehn[8] embolized dogs in an attempt to recreate the "reflex" type death which they believed to be one of three types occurring in humans. They succeeded only in reproducing the other two, acute death due to massive obstruction and more prolonged death due to less massive initial obstruction which increased with time. They showed carotid artery and right ventricular pressure tracings and described most results obtained by subsequent workers. In 1917, Mann[9] embolized awake, locally anesthetized, and anesthetized dogs with paraffin or blood clots. Complete blockage of the main PA caused precipitous falls in systemic pressure, whereas gradual declines followed when most of the branches were occluded and clots formed around the emboli. Vagal sectioning did not alter the responses. He concluded that it was impossible to kill or imperil life by emboli until the circulation was greatly obstructed. Dunn,[10] in 1920, reported experiments performed during World War I in which starch particles were injected into goats in an effort to understand the mechanisms of gas poisoning. These are of historical significance because they initiated

the use of minute particles (a source of confusion, as will be seen) into the experimental approach to "pulmonary embolism."

Several groups have investigated how much limitation of flow is necessary to account for the effects of emboli. Haggert and Walker[11] reported that, by gradual occlusion of the main PA in anesthetized cats, from 52 to 66 per cent of the flow had to be cut off before there was significant variation in general circulation. At this rather precise end-point they observed right heart dilation, decreased output, and a fall in systemic pressure. Hall and Ettinger[12] found 75 per cent occlusion necessary to initiate circulatory collapse in dogs. In addition, faradic stimulation, externally and internally along the PA and its branches, and stretch, with and without occlusion, all failed to cause circulatory changes relatable to reflex activity. They concluded that in dogs only massive obliteration caused death. Steinberg and Mundy[13] embolized dogs with lead shot followed by an opaque material, and concluded that at least 79 per cent had to be blocked before serious consequences ensued, and that their experiments did not justify the concept that multiple emboli, as such, caused either immediate or delayed death by their presence in the lung or by a reflex. Similar results were reported for cats.[14] Mendlowitz[15] embolized dogs with $BaSO_4$-filled rubber tubes, and concluded, "We are therefore dealing with a type of hypokinetic circulatory failure distinct from others hitherto described. It is neither neurogenic, hematogenic, vasogenic or cardiogenic. It is due to a major obstruction in one portion of the double circuit which comprises the mammalian blood-vascular system."

The method of isolation of one lung's vasculature has been employed by several investigators. Schweitzer[16] raised the pressure in one PA and concluded that this failed to cause noteworthy changes in systemic pressure or cardiac activity. Williams[17] carried out similar experiments as part of a study on embolization in over 50 dogs with known amounts of 60μ glass beads. In addition, he checked the effects of surgery and drugs and concluded that evidence for reflex pulmonary vasoconstriction was lacking and that eventual right heart failure and death could be explained on mechanical grounds alone.

Lochhead, Roberts, and Dotter[18] reported angiocardiographic studies from 6 dogs embolized with thrombin-induced clots of each animal's own blood, followed by 75 per cent Neo-Iopax. Films were taken at 2-second intervals before embolization and at ½, 1, 2, 3, 4, and 5 minutes thereafter. The average PA caliber was compared at four points in each film. All clots were found in vessels smaller than the main PA. The authors concluded: "The most striking finding . . . was the demonstration of pulmonary artery dilation, beginning at 20 seconds and lasting at least 5 minutes. At no time was it possible to identify changes which were thought to demonstrate constriction of the pulmonary arteries."

Many efforts have been made to implicate the vagus in such a reflex. Walsh[19] isolated individual vagal fibers which were dramatically affected during pulmonary embolization, and which he thought originated from PA walls. Paintal[20] showed, however, that the fibers originated from the right or left atrium. Griffin and Essex[21] evaluated the effect of removal of the sympathetic chain and bilateral

vagotomy on starch-injected rabbits and starch- and $BaSO_4$-injected dogs and found no neurogenic factors. They found starch granules in cardiac muscle and brain, but do not mention looking for $BaSO_4$ outside the right heart and pulmonary vessels.

Megibow, Katz, and Steinitz[22] reported embolization of dogs with 3 sizes of emboli. No reference was made to reflex vasoconstriction regarding the effects of the largest, and they stated that the most likely explanation for the progressive hypertension found with the medium-sized emboli was, " . . . increasing obstruction occasioned presumably by the addition of ante-mortem thrombi upon the pea seeds, or much less likely by a reflex pulmonary vasoconstriction." Starch granules were employed as "minute emboli." In discussion the authors stated, "Essentially one primary mechanism is operating in the death of all these animals. We believe that the primary fault lies in the presence of a foreign object, the embolus in the pulmonary arterial tree. This object acts as a direct mechanical deterrent to the blood flow through the pulmonary circuit." Hara and Smith[23] reported that neither embolization of dogs with particles from the size of navy beans to 500μ seeds, nor the inflation of ballons in a PA to a pressure of 300 mm. Hg, caused any significant effect on pulmonary or systemic artery pressure or cardiac rate. They commented, "It would stand to reason, therefore, that sudden death or immediate distortion of cardiovascular function may not be likely to occur following emboli to the larger lobar vessel systems unless critical mechanical obstruction is established."

Many reports which have found supposedly positive results with fine particles have also found negative ones with large emboli. In 1935, Villaret, Justin-Besançon, and Bardin[24] embolized dogs with 3 sizes of particles. With the "massive" emboli (enamel beads the size of the jugular) and with "medium" ones (large mucilage granules) it was difficult to kill. However, a "minimal amount" (never defined) of powdered pumice stone caused death within a few minutes. Those particles which passed through a sieve with 150μ openings were employed as the embolic material. The authors assumed that only pulmonary arterioles had been embolized and that irritation of their walls caused, locally, vasomotor disturbances and, at a distance, an inhibition of respiration and heart; they concluded that sudden embolic deaths resulted from such reflex stimulation. Villaret's group published several other papers on pulmonary embolism, including a "Rationale of Therapy," and all were based upon these methods. In 1939, Violet[25] reviewed the clinical and experimental evidence regarding reflexes from pulmonary emboli and analyzed Villaret's methods, results, and conclusions. Violet showed that when pumice powder was sieved, as had been done by Villaret, one fourth of the total *weight* of the injected material consisted of particles 1-5μ in diameter, rather than 150μ as had been assumed. When Violet removed the very fine particles and embolized with pumice stone 100-200μ, no apparent distress occurred in dogs or guinea pigs until enough was injected to cause considerable mechanical obstruction. Violet thus demonstrated that the very fine particles were necessary for the dramatic results and that the major experimental support for the French clinical opinion of the nineteen-thirties, regarding the existence of reflex embolic spasm, was based upon a misinterpretation of results.

However, it was the clinical opinion which became known in this country (see abstract of Villaret's work in Foreign Letters of the J.A.M.A. 107:1063, 1936; and the works of René Leriche, cf. Ref. 38, for example). The significance of Violet's work in relation to the ideas about pulmonary embolism, and particularly the experimental approach to it, has continued to be neglected because the work has been repeatedly mistranslated.

Binet and Burstein[26] embolized dogs with $BaSO_4$ and Lycopodium spores and found that these materials (in unstated amounts) raised PA pressure higher than ligation of one main branch. The authors asked whether this should be attributed to obstruction or reflex vasoconstriction, and assumed the latter. No reference was made to any previous work. Several abstracts[27-29] have been repeatedly quoted in support of reflex spasm. Haynes, Kinney, Hellems, and Dexter[27] reported that a balloon dilated within a lobar artery to pressures higher than PA pressure produced no consistent respiratory, PA, or femoral artery pressure changes in anesthetized or unanesthetized dogs. These authors reported, however, that Lycopodium spores infused "into the pulmonary artery to only one lobe" in anesthetized animals regularly produced increased respiratory rates, pulmonary arterial and right ventricular pressures, together with ECG changes and decreased femoral artery pressures. The authors stated that the changes were not abolished by vagal sectioning or pithing of the spinal cord, and that they led "to death if the embolus was continued." Smith and Hara[28] obtained negative results when care was taken to prevent retrograde passage of infused Lycopodium spores, glass beads, and poppy seeds. However, these authors found, "In contrast, the injection of very fine material, such as starch or $BaSO_4$ suspensions, into the lobar artery produced a marked rise of pulmonary arterial pressure, a precipitous fall of systemic blood pressure, and intense distention of the right heart. Death occurred in 2 to 3 minutes." They reasoned that, " . . . pulmonary 'capillary' emboli, affecting a restricted portion of the pulmonary vascular bed, may cause death with apparent pulmonary spasm and circulatory failure." These authors reported similar findings elsewhere.[29] These supposedly positive results must be considered in the light of later work. In 1951,[30] Daley, Wade, Maraist, and Bing reported that Lycopodium spores caused PA pressure rises only if they were allowed to spread throughout the lung, that pressures were related to the amount infused, and that vagotomy, anterior rhizotomy, and sympathectomy did not affect the response. They concluded that the hypertension was probably dependent upon degree of mechanical blockage and uninfluenced by any known nervous pathway. In 1956, Courtoy and Salonikides[31] reported on embolization of dogs with Lycopodium spores and concluded that the pulmonary hypertension was primarily due to mechanical obstruction of pulmonary arterioles; no evidence was found in favor of the concept of a pulmonopulmonary constrictor reflex. We demonstrated that, when glass beads were infused into one lobe until death, beads were recovered from every lobe, and that starch and $BaSO_4$ can pass through the lung, and we do not think that the positive conclusions are necessarily supported by the results.

Byrne, Isales, and Hickey,[32] and Byrne[33] used the number of arteries, 20μ and larger, containing injected 5μ graphite particles as an indicator of the effect

of anesthesia on reflex embolic vasoconstriction. Unless the possibility of intravascular clumping of such foreign particles was experimentally ruled out, we do not believe that the intra-arterial distribution necessarily indicates presence or absence of vasomotion. Price, Hata, and Smith[34]; Laurent and associates[35]; and Rodbard and Katz[36] recently reported findings which the authors concluded gave evidence of reflex pulmonary vasoconstriction. Because these experiments utilized $BaSO_4$ or starch granules as the embolic material, we believe that the authors' conclusions may not necessarily be supported by the results. Niden and Aviado[37] attributed two findings in dogs to reflex constriction from small glass beads. The first was that, while 250-420μ beads caused only a sharp rise in PA pressure, 60-200μ beads caused an additional gradual rise. In our opinion the most likely explanation of this is that the smaller beads added on precipitate proximally and blocked nearby capillaries, while the larger beads lodged in deeper arteries where much more clot had to form before it additionally limited flow. The second finding was that beads injected into a part of the lung perfused by the animal's own heart caused a pressure rise in a pump-perfused segment of lung. The published tracing shows an approximate 1 mm. Hg rise. In our opinion, unless the pump-perfused portion was specifically examined for beads, a minor scatter to that part could account for a change of this magnitude.

In 1937, Leriche, Fontaine, and Friedmann[38] published a paper referred to as though it supports reflex vasoconstriction. The only new data concerned a patient in whom stellate ganglion block failed to prevent death. The introduction stated, "As seemingly true as it is, the reality of this spasm demands to be proven." However, because Leriche and others were convinced that embolic spasm did occur and that surgery and drugs, papaverine in particular, relieved this "response," therapy was, and still is, directed along these lines, as evidenced by the following quotes from current texts on surgery and pharmacology. "When an embolus lodges in a major branch of the pulmonary artery, as when an embolus lodges in a peripheral artery, a certain degree of spasm of the arterial tree occurs and, in the lung, also bronchial spasm . . . Treatment therefore should be designed to combat these factors . . . papaverine in half grain doses intravenously will help relieve the arterial and bronchial spasm . . ."[39] And, "In the presence of pulmonary embolism, papaverine dilates the pulmonary vessels and in this manner exerts a salutary effect in this disorder."[40] In our opinion, the experimental data do not support this supposed pharmacologic action of papaverine.

Macht,[41] in 1916, studied the in vitro effect of papaverine on arterial rings or strips and stated, "Whereas the coronary arteries, the carotids and subclavians and internal and external iliacs were markedly relaxed by the drug, the pulmonary artery was but slightly dilated and the uterine arteries still less so." In 1939, deTakats, Beck, and Fenn[42] evaluated drugs, O_2, and bilateral vagotomy as protection of rabbits and dogs from emboli. A 2.0 c.c. lethal dose of starch suspension was established for rabbits. Although a dose of 4.0 c.c. was necessary to kill when O_2 was administered, papaverine and atropine offered no protection. Dogs were either pretreated with drugs or vagotomized, and then embolized and compared with others with no pretreatment. From the text it is

clear that some pretreated animals survived longer than untreated ones and, although the survival times were not given, it appears from the text that all animals died. However, in the tabulated results, there appears the term "percentage of fatality." This figure represents some assumed protection of the dogs and apparently is based upon the unstated survival times. Because these necessary data are not given, it is not possible to evaluate the authors' discussion and conclusions. Bradshaw and Chodoff[43] measured PA pressures in 24 cats before and after eupaverine (considered phamacologically similar to papaverine), mineral oil embolism, and mineral oil followed by eupaverine. In all animals, eupaverine alone caused a rise in PA pressures and sublethal oil caused greater rises, but the highest pressures were recorded when eupaverine was given to embolized animals. Jesser and deTakats,[44] using x-ray films, studied the action of papaverine on pulmonary vessels of unembolized dogs or following embolization with a mixture of iron perchloride and $BaSO_4$. A control film was taken and, 5 minutes after an injection of 0.12 Gm. papaverine HCl, a second exposure was made. The authors stated, "Note the widening of the superior vena cava, the enlargement of the right side of the heart and of the pulmonary conus. The diameter of two arterial branches running toward the spine and the diaphragm is definitely larger after administration of papaverine." In another animal, following a control and a postembolization exposure, a third film was taken after 0.06 Gm. papaverine. The authors stated, "Note the marked change in the vascularity of the upper and the lower lobe. There is more vascularity than in the control film." In comment they stated, " . . . we believe that we have demonstrated increased vascularity following the use of papaverine, a hitherto unsettled question. Whether this means a relaxation of the smooth muscle of the arteries or is due to a rise in pulmonary arterial pressure could be settled only by direct measurements of pressure in the pulmonary artery." Such measurements were made in 6 experiments on 2 unanesthetized, unembolized, trained dogs, in 1943, by Friedberg, Katz, and Steinitz.[45] Papaverine consistently raised PA pressure and lowered systemic pressure. Katz,[46] in 1945, stated, "Experimental evidence is clear in showing that papaverine relieves the narrowing of the pulmonary bed; it overcomes the pulmono-pulmonary reflex constriction." Although this paper has been cited as evidence for reflex vasospasm and the utility of papaverine, the author presented no new data. Holden, Shaw, Cameron, Shea, and Davis[47] reported pressures from the carotid arteries and right atria of 36 dogs before and after embolization with large thrombin-induced clots of each dog's blood. Most experiments concerned possible protection from embolic insult by vagotomy and sympathectomy, and in this regard the authors stated, "So far as a pulmono-pulmonary reflex is concerned, there is no evidence in this study that such exists . . . In animals that succumb, systemic pressure becomes progressively lower and right atrial pressure higher. These animals all have at least 70% of the pulmonary circuit mechanically obstructed." In regard to papaverine, similar tracings were made on 3 dogs before and after the drug alone, and after embolization with clots, followed by the drug. Papaverine caused transient reduction in pressure in all pairs of tracings, interpreted as probably resulting from generalized systemic arterial and venous dilation rather than relief of a localized PA spasm.

In our opinion, these data on papaverine's action on pulmonary vessels do not justify the belief that the drug relieves an embolic spasm. Rather, we think that all available knowledge about this drug should be re-evaluated in relation to the report of Sagall and Dorfman.[48]

Inherent in many reports which have obtained dramatic responses with small particles as "pulmonary emboli" has been the presumption that too little material was employed to account for the results on a mechanical basis alone. W. S. Miller,[49] in 1893, reported data relevant to the embolic potential of small particles. He gave the number, diameters, and cross-sectional areas of all branchings of the pulmonary arteries of 7-kilogram dogs. He found 192,000 atrial and sac arteries, 165μ in diameter, from which all capillaries arose. These arteries had a total cross section of 4,032 sq. mm. and gave off 600 x 10^6 capillaries, with an average diameter of 7μ, and a total cross section of about 23,000 sq. mm. Although we do not have similar data for rabbits, we assume that the anatomic divisions were not larger in our approximately 2-kilogram rabbits than those in 7-kilogram dogs. The 0.50 Gm. lethal dose of 50-150μ beads for 2-kilogram rabbits contained approximately 415,000 beads with an average diameter of 96μ, giving a total cross section of approximately 3,000 sq. mm. This rough calculation demonstrates that even in the absence of added precipitate the lethal dose can represent a considerable mechanical blockage.

Several remarks can now be made regarding the first main point which has kept alive the belief in this reflex, the finding of small emboli at autopsy. A considerable clinical and pathologic literature on pulmonary embolism exists. This literature emphasizes that, in most instances, death from pulmonary embolization does not occur unless a large portion of the circulation is obstructed; however, in severely ill patients, particularly with congestive failure or lung disease, small emboli and infarctions are found. In our opinion, it is not surprising that insults to the body which are tolerated in health can cause more severe results in the critically ill; however, such findings cannot be used as solid support for the concept of reflex vasoconstriction.

SUMMARY AND CONCLUSIONS

A current belief exists that pulmonary emboli can cause fatal reflex pulmonary vasospasm and that certain animal experiments support this concept. Direct in vivo microscopy, with magnifications from 16 to 900 times and quartz rod transillumination, has been used to study the lungs of 66 rabbits and 13 cats during embolization with 10 to 2,000μ particles or with air bubbles. These observations were related to others, obtained with similar embolization in 67 rabbits, 4 cats, and 12 dogs. The particles used in a majority of the experiments were 50-150μ glass beads, because (1) these sizes lodged within visible arteries, making processes associated with their arrest observable, and (2) this size particle is within the range which has yielded conflicting results in the past.

Killing amounts of 50-150μ beads were the same in awake, anesthetized, thoracotomized, medicated, and vagotomized rabbits. This amount of beads was not per se fatally toxic but was tolerated if injected over longer periods of time.

Unembolized arteries never decreased in diameter; rather, either an increase or no change was observed, with their linear flow rates behaving similarly. Em-

bolized arteries never decreased in diameter proximal to the plug, and did so distally only when collateral flow into that segment was markedly reduced or stopped. That such reductions distal to emboli could be misinterpreted as "reflex constriction" was pointed out. A white precipitate sometimes embolized pulmonary arteries before particles were injected, and sometimes concomitantly with particles. Similar precipitate usually surrounded each bead and frequently bound several into large masses. A similar material "grew" on lodged emboli and thereby further mechanically blocked flow. The fatal "lobar" injection of beads demonstrated at autopsy that scatter to all lobes had occurred.

In our opinion, the best interpretation of the cause of death from these emboli is that they mechanically blocked the pulmonary vessels. No observation necessitated the invocation of reflex vasoconstriction for its explanation.

In mesenteric veins, precipitate (1) formed immediately on beads, (2) stuck beads together, and (3) formed slowly on catheter tips. In vivo observations of lungs at varying times following sublethal embolization demonstrated progressive clearing of induced precipitate and exclusion of beads and spores from the blood vessels.

It was demonstrated that starch granules and $BaSO_4$ can pass through the lungs of rabbits, cats, and dogs.

By rough calculation and reference to the anatomy of the dog, it was shown that the lethal dose of 50-150μ beads for rabbits represents a large embolic potential.

The animal-experimental literature relevant to the hypothetical reflex was discussed. It is largely an accumulation of negative evidence, particularly so for all but small particles. Violet demonstrated one source of error with the use of small particles as "pulmonary emboli." Nevertheless, such materials have continued to be a source of conflicting results. The following observations are relevant to interpreting results obtained with such materials: fine particles can pass through the lung, can represent a very large cross-sectional area, can evoke the formation of a precipitate on their surface, can stick together, can cause hemolysis, can flow backwards around a catheter and embolize uncatheterized lobes, can enter the tips of pulmonary arteries where the formation of additional precipitate proximally directly blocks off more flow, and can be "removed" from pulmonary blood vessels after a period of time.

The original articles on the pharmacology of papaverine do not support the textbook opinion that this drug causes a reduction in pulmonary vascular resistance, either in the presence or absence of pulmonary emboli.

The clinical and pathologic literature on human pulmonary embolism emphasizes that fatal outcome is usually caused by massive mechanical blockage, although lesser emboli may be found in the presence of other debilitating disease.

In our opinion mechanical blockage is the cause of death in pulmonary embolization.

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THE VENTRICULAR ACTIVATION AND THE VECTORCARDIOGRAPHIC CURVE

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SO FAR as we know, nobody has attempted a correlation between the sense of the vectorcardiographic loop and the sequence of the activation process of the heart. It needs to be affirmed whether or not a relationship exists between curves recorded at a distance and those events produced on the surface or within the mass of the heart.

The electric vectorial analysis based on distant points of exploration is quite different from that developed from proximal points. Most investigators[1,2] concede that when one works at a distance, all cardiac charges can be represented at any given moment by a single vector. This unique instantaneous vector is considered as a dipole. The general theorem of which this is a special case is known as Stratton's theorem of equivalence.[3]

The vector representing the dipoles which are actually present in the heart are of the fixed, polar variety. The points of application of these vectors according to the dipole theory are the sinks of current closest to the crest of the wave of activation. This wave crest may be considered at any given instant as extending into various regions of the cardiac musculature. Numerous small vectors are set across, or straddle, this activation crest, all of them being fixed to different points. Thus, we may speak of a vectorial function of points; putting it another way, the field of the heart is a vectorial field.

Fixed vectors, such as those considered in the heart, do not lend themselves to elementary operations; as an example, the well-known parallelogram law used in vector addition no longer pertains. This observation must be applicable in the case of the vectorial field studied by direct leads. When the same field is studied from afar, the distance separating the points of application of the vectors is reduced to a minimum, and by applying Stratton's theorem the vectorial sum could be calculated. When this process is actually carried out, the sum becomes coincident with the expression for a dipole contained within a homogeneous media; thus is the underlying concept of the Einthoven hypothesis.[1]

There are facts which suggest a correlation between the sense of the VCG loop and the order of the activation process: (1) The inscription (clockwise or counterclockwise) of the VCG loop varies in the frontal plane according to anatomic rotation of the heart about its longitudinal axis. (2) In bundle branch block

Received for publication Feb. 23, 1957.

the VCG curve is oriented toward the delayed ventricle. (3) In myocardial infarction the VCG curve aligns itself in a direction pointing away from the inactivated zone.

The Normal Vectorcardiogram in the Horizontal and Sagittal Planes.—The majority of authors[4,5] are in accord as to the constancy of the sense of development of the normal VCG in the horizontal and sagittal planes.

In the horizontal plane the normal VCG develops in the counterclockwise sense, while a clockwise rotation should be considered definitely abnormal.

The vectorcardiographic curve inscribed in the sagittal plane normally develops in a counterclockwise sense.* Although the sense of the loop is quite constant, it does not approach the invariability of counterclockwise rotation in the horizontal plane.

Magnitude of the Electrical Potentials of the Heart.—Undoubtedly, in the normal human heart the major potentials are those corresponding to the left ventricle. However, our experiments on the dog's heart show that outright left ventricular predominance is not as obvious as in the human. Actually, considerable positive deflections are encountered over the middle, basal, anterior, and posterior aspects of the dog's right ventricle.

In the human heart circumstances are somewhat different from those in the dog's. The electrical potentials generated in the human right ventricle are small in comparison to those of the left. One of us (E. B.[6]) recently studied the morphology and magnitude of tracings recorded from the human epicardium. The greater part of the points explored over the right ventricle revealed an rS type complex; complexes of the R type were relatively rare, being found mainly over the basal portions of the ventricle proximal to the A-V groove. On the other hand, the deflections over the left ventricle were principally positive; the ratio of the magnitude of the positive deflections of the left ventricle to those of the right was 9.6/1.

The predominant left ventricular potentials are manifest throughout the greater part of the ventricular depolarization process. When the total cardiac cycle is considered, other potentials must be taken into account. The earliest ventricular activation commences in the septum[7]; this force initially would be unopposed as the stimulus has yet to invade the free left ventricular wall. As the activation process comes to an end, it would appear that right ventricular basal potentials exceed all others. This concept receives support in the vector analysis of Tranchesi and Peñaloza,[8] and also from the direction of the terminal loop of the vectorcardiogram. The above-mentioned left ventricular forces are paramount during the prolonged intermediate phase of the activation process.

Extensive studies have been carried out at the Instituto Nacional de Cardiología de México on the nature of the activation of the free wall of the left ventricle.[9,10] It is now known that the first regions to become activated are proximal to the apex, while the last are located basally.

It is reasonable to suppose that the maximal resultant instantaneous left ventricular potentials are located somewhere within the middle portion of the wall, equidistant from the anterior and posterior left septal insertions (Fig. 1). The locus of the instantaneous "centers" describes an arc going from apex to base. The large deflections obtained over the left ventricular wall would seem to support this concept.

If the potentials are such as is supposed, then it is easy to explain the counterclockwise rotation in the horizontal and sagittal planes. The unique position of the left ventricle would hardly allow it to be otherwise.

Distribution of the Electrical Potentials of the Heart.—According to Stratton's theorem,[3] when recording at a distance, the electrical charges of the heart can be represented as a dipole; moreover, the relative magnitude and direction of this dipole are readily ascertainable. The various constants encountered in the Stratton equation express the position and moment of the dipole, and, in turn, these constants depend on the charge distribution within the heart. Clearly then, it is only by knowing the charge distribution that any correlation, if such exists, can be found between

***In this article the trigonometric convention will be adhered to; thus, the sagittal plane is viewed from within outward: This is contrary to the convention employed by Grishman et al.,[4] according to which that author describes predominantly clockwise rotation in the sagittal plane.**

vectors registered at a distance (vectorcardiogram) and the electrical phenomena produced within the heart. The above—mentioned equation theoretically would indicate that, as the exploring electrode approaches the heart, the influence of multipoles (quadrupoles, octupoles, etc.) could no longer be discounted, resulting in a possible loss of similarity between distant and close leads.

Within the heart it is not possible to summate vectors by the parallelogram law, but it is possible to form an approximate idea of the distribution of charges. This can be done by a study of the "Gaussian potential."*

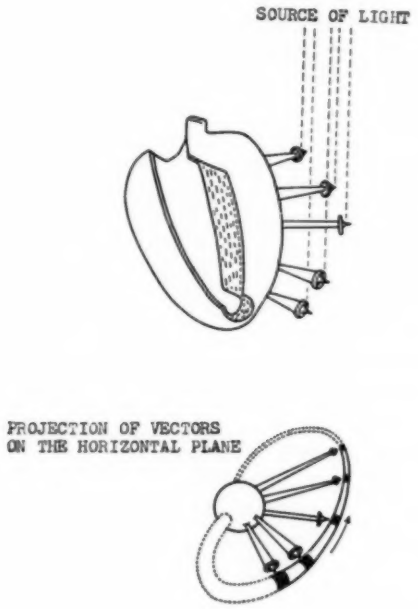

Fig. 1.—Schematic representation of the sequence of the activation process in the free left ventricular wall. The locus of the instantaneous "centers" describes an arc going from apex to base. Notice that the sequence and the anatomic position of the left ventricle explain the counterclockwise rotation in the horizontal plane.

Both the superficial epicardium and the endocardium of the dog's heart were studied using a cathode-ray oscilloscope to find the maximum positivity (source) and negativity (sink) during the cardiac cycle. The mensuration of potential was done for each 0.005 sec. The first reading was taken arbitrarily at the point in time corresponding to the initial portion of the QRS complex in Lead II. This is really an arbitrary point, for prior to its inscription frank potential variations are detected over the superficial epicardium.

In Fig. 2 the results of one such experiment are seen. This recording is representative of many such experiments conducted.

The first site of maximum positivity (or the first "source" of current in the superficial epicardium) is located in the mid-part of the trabecular zone (0.00 sec. in Fig. 2). This finding had already been noted by Schaefer.[11] At the same time maximum negativity is recorded in the middle portions of the left ventricular cavity.

About 0.005 sec. (Fig. 2) after the initial deflection in Lead II, the maximum positivity is located in the free right ventricular wall in a portion of the trabecular zone even more to the right than in the previous case. The corresponding locus of negativity continues to be the left cavity, proximal to the apex.

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*Frank N. Wilson[12] gave the meaning of "Gaussian potential" as follows: "A part of an excitable tissue which has been 'injured' in any way which will prevent it from responding to the excitatory process can yield no 'action potential,' but its 'Gaussian potential' can change as a result of electromotive forces arising in other parts of the tissue."

At 0.01 sec. (Fig. 2) the location of maximum positivity is now in both the trabecular zone and the paraseptal region of the anterior wall of the left ventricle near the apex. The appropriate sinks are still within the left cavity.

By 0.015 sec. the major source has shifted to the apex of the left ventricle, with its sink being in the left cavity (Fig. 2). The situation is practically unchanged at 0.02 sec., the greater source being over the anterior part of the free wall of the left ventricle (Fig. 2).

Later, at 0.025 sec. both the trabecular zone and apex of the left ventricle become sinks. However, in this instance two important sources are noted, one in the high, lateral portion of the left ventricle, and the other in the mid-superior portion of the anterior wall of the right ventricle, near to the auricular ventricular groove (Fig. 2).

At 0.030 sec. the maximum source is now near the conus of the right ventricle. Still important, but to a lesser degree, is the positivity recorded over the high anterior paraseptal portion of the left ventricle. The apex still contains the greatest sink.

Somewhat later, at 0.035 sec., the situation remains unchanged (Fig. 2). From this time onward (0.040, 0.045, 0.05, 0.055 sec.) the major source is consistently located in the high, lateral portion of the left ventricle. The last source to be extinguished is contained also within this location. Maximum negativity corresponding to this terminal interval is in either the posterior wall of the left ventricle (Fig. 2) or in the anterior basal region of the right ventricle.

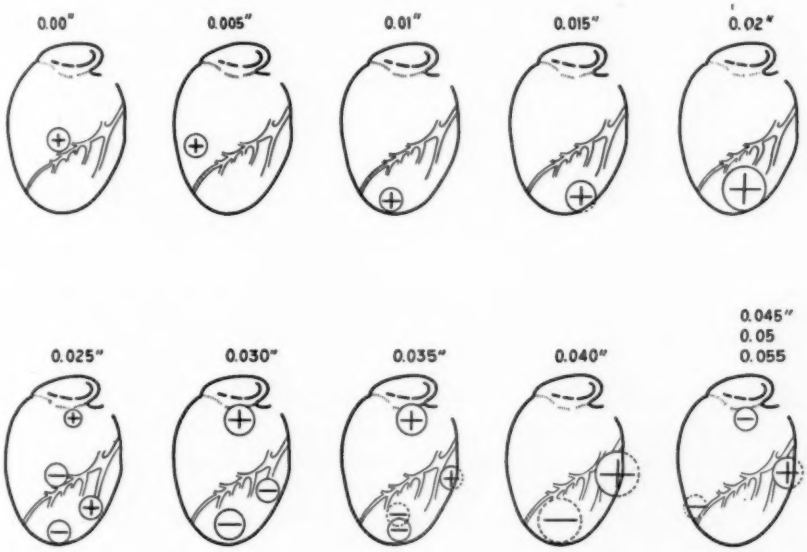

Fig. 2.—Sites of maximum positivity (source) and of maximum negativity (sink) at the epicardial surface in the normal dog's heart. (Areas in dotted circles correspond to the posterior aspect of the heart.)

Significance of the Maximum Sink and Source Determined in the Heart at a Given Moment.— It is more or less apparent that had we been able to determine the specific location of both maxima sink and source we would have established in fact the true maximum potential gradient of the heart. It should be appreciated that our study at best is limited by certain unavailable experimental features. It is quite impossible to explore every point in the heart, and for that reason we limited ourselves to an exploration of the epicardium and endocardium, along with intracavitary leads. Since a degree of imprecision is introduced by these limitations, it would be more correct to speak of the "apparent" instantaneous maximum potential gradient. There can be no doubt that were it possible to determine the potentials within the mass of the heart the maxima alluded to above would be in many instances intramural and quite near to the activation wave. The distance between source and sink would certainly be less than the figures we established experimentally.

Since a potential gradient is a vector, it is legitimate to consider the instantaneous gradient running from maximum sink to source vectorially. We called this vector the "apparent maximum potential gradient."

Spatial Orientation of the Vector Called the "Apparent Maximum Potential Gradient."—We devoted special attention to the position of this "apparent maximum potential gradient," at 4 different times during the cycle. This gave us 4 vectors, each of which represents a different portion of the cycle.

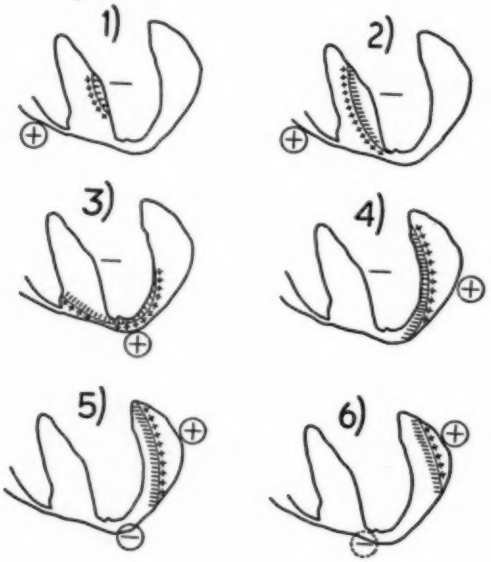

Fig. 3.—Correlation between the sites of maximum positivity and negativity (apparent maximal potential gradient) and the process of ventricular activation in the interventricular septum and the free left ventricular wall.

The first instantaneous vector that we determined has its point of origin in the mid-portion of the superficial surface of the left septum and terminates in the trabecular zone. Thus, this vector is directed forward, to the right, and slightly downward (0.00 and 0.005 sec. in Fig. 2). Somewhat later (0.01, 0.015, and 0.02 sec., Fig. 2) the next instantaneous vector originates at the same point, but now its termination is in the apex of the heart. It runs slightly forward (note that the experiments were performed in the dog's heart) but more distinctly downward than the last, veering in this case very slightly to the left. In the next period (0.025 and 0.030 sec.) an abrupt change in vectorial direction occurs, with the apex now becoming the maximum sink. The associated sources were located within the high, anterior free wall of the left ventricle. We eliminated the sources near the conus to approximate more closely the human condition.

In the succeeding moments (0.035, 0.040, 0.045, 0.05 sec., Fig. 2) the vectors generally were directed from below upward, backward, and to the left. The sources were located in the high lateral wall of the left ventricle, while the corresponding sinks were in the posteroinferior portions of the free wall of the left ventricle.

Correlation Between the "Apparent Maximal Potential Gradient" and the Process of Ventricular Activation.—In the previous section, 4 principal vectors were described from the point of view of their direction and temporal sequence. Interestingly enough they gave a good approximation of the general process of activation as it develops within both the interventricular septum and the free wall of the left ventricle. The first of these 4 vectors found its point of origin in the superficial mid-left septal surface and was directed toward the trabecular zone (Fig. 3) This direction would be given by activation of the middle left septum which is known to be the first portion of the heart to become activated.

The second vector has the same points of origin but was directed toward the apex of the left ventricle and adjacent regions of the left anterior wall (Fig. 3, *3*). Subsequent to the activation of the lower left septum, the activation wave fans out as it spreads to the apices of both ventricles; in so doing a composite leftward direction is given because of the dominance of the left apical forces over those of the right. Thus, the second vector neatly fits the experimentally established facts.

The third vector studied began in the left apex and was directed toward the high lateral portions of the free wall of the left ventricle (Fig. 3, *5*). It should be stressed that this does not imply that because the vector's point of application is at the apex, the activation process commences in the superficial apical epicardium. The given direction is so expressed because of the inherent limitation of the method of exploration, i.e., confining recording points to the epicardium and endocardium.

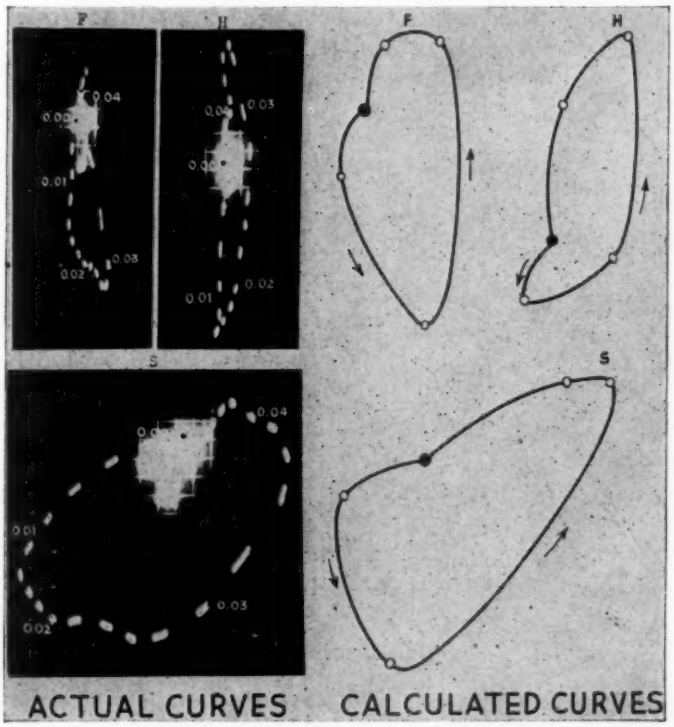

Fig. 4.

Analysis of the fourth vector imposed the same limitations just discussed for the third vector. It corresponds to the activation of the highest or most basal portions of the left ventricle (Fig. 3, *6*). Were this so, then the greatest sources should be found in this area. This proves actually to be the case. The corresponding "sink" which is just behind the front of the activation wave would be located theoretically in the high intraventricular mass or deep within the myocardium of the basilar region of the left ventricle. The latter areas were not explored for reasons given previously. The "sink" determined would project itself to the superficial epicardium and thus come to lie on the posterior wall of the left ventricle near the apex; a position diametrically opposite to the source.

In conclusion, suffice it to say, that a good correlation exists between the ventricular activation (excluding potentials arising from right ventricular activation) and the vector representing the "apparent maximal potential gradient."

Magnitude of the Vector "Apparent Maximal Instantaneous Potential Gradient."—In the experimental work referred to, it was possible to estimate only roughly the magnitude of the 4 vectors mentioned. It is implied that sufficient care was taken in standardization so that the

values of the potentials at the apparent greatest "sources" and "sinks" could be compared. In order to estimate the magnitude of the vectors, the algebraic difference of the values for the positive and negative potentials was calculated, but we were not able to determine the distance that separated said potentials. Since this distance was different for each vector, the magnitudes cannot be considered to be quantitatively accurate. The magnitudes used for the four vectors were: septal vector, 18 mm.*; vector of the apex of the left ventricle, 54 mm.; vector of the free wall of the left ventricle, 68 mm.; vector in the base of the free left ventricular wall, 36 mm.

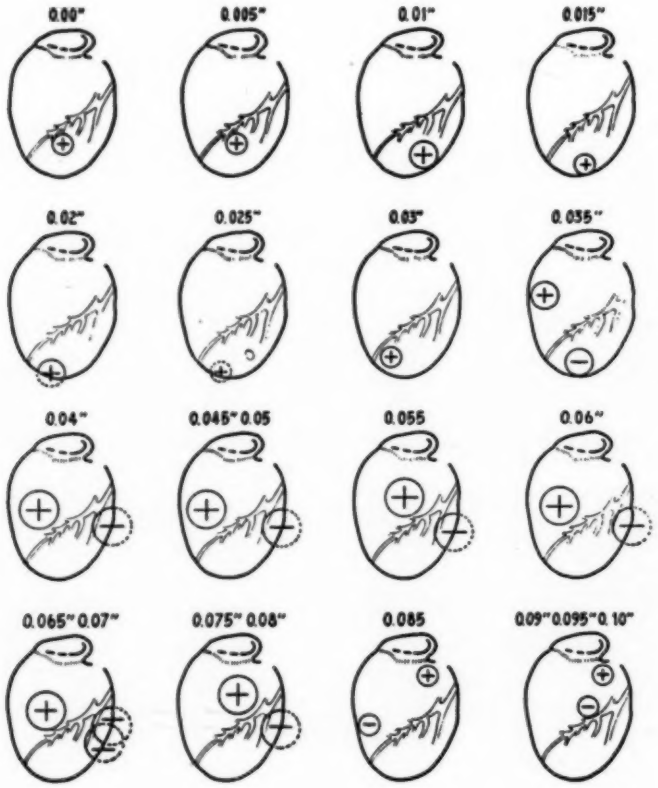

Fig. 5.—Sites of maximum positivity (source) and of maximum negativity (sink) at the epicardial surface in the dog's heart after the right bundle branch was severed. (Areas in dotted circles correspond to the posterior aspect of the heart.)

Calculated Vectorcardiographic Curves From the Vector "Apparent Maximum Instantaneous Potential Gradients."—Small sticks of wood were cut to correspond to the size of each vector and these pieces was embedded in a wax ball. This was placed in front of a light source and the image was projected in 3 planes, frontal, horizontal, and sagittal. Three curves were drawn from each model (Fig. 4), one for each of the planes.

It should be remembered that the potential difference used in estimating the magnitude of the apparent maximum potential gradient is determined from the potentials at the apparent maximum source and sink. This potential difference is less than the potential difference between the true maximum source and sink. If the apparent source or sink is at a considerable distance from the true source or sink, this discrepancy may be quite large. Hence, one should not expect the details of size and shape of the calculated vectorcardiographic loop to agree very precisely with those of the peripherally determined vectorcardiographic loop. On the other hand, the direction

*The standardization used is immaterial as long as it remains the same during the whole experiment.

of the apparent maximum potential gradient vector may be expected to be similar to the direction of the electrical axis as peripherally determined. If this be true, then, at any instant, the direction of rotation should be nearly the same in both loops, and both should be inscribed in the same general direction.

The 3 curves from the wax ball are indeed similar, generally speaking, to those obtained from the animal, considering (1) the discrepancy between the apparent and true maximum potential gradients, and (2) the added difficulties of constructing a cube from the shape of the chest of the dog. In the calculated curves, the posterior and high portions are larger than in the actual curves (Fig. 4).

The Vectorcardiographic Curves in Relation to the Direction of the Process of Activation.—In all the actual curves, as in the calculated ones, the direction of the first portion of the curve, considering the 3 planes, was forward, downward, and slightly to the right (Fig. 4). The same direction is found in the process of activation which originates, in the dog's heart, in the middle portion of the left septal surface and ends in the base of the anterior papillary muscle in the right cavity, remembering that the dog's heart is rotated a great deal in the clockwise sense and is vertical.

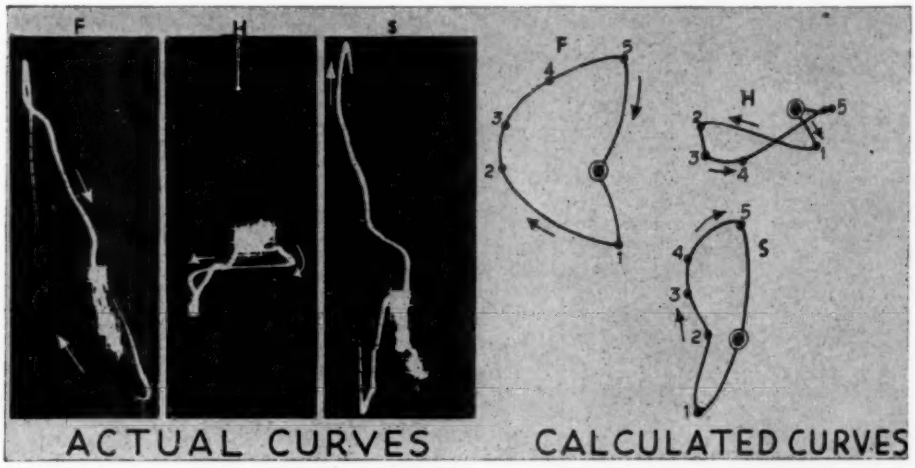

Fig. 6.

The second portion of the curve, obtained from the method of the cube, is downward, forward, and slightly to the left. This finding corresponds very well to the direction of the process of activation as it invades the apical portion of the left ventricle. In the calculated curves, the second vector is oriented more to the left (Fig. 4) in the horizontal plane; however, the whole sense of activation, generally speaking, is satisfactory enough.

Later on, the actual and calculated curves appear to be oriented backward, upward, and slightly to the left. Again the concordance with the process of activation in the free wall of the left ventricle is quite satisfactory.

Maximum "Sources" and "Sinks" in a Case of Experimentally Produced Right Bundle Branch Block.—The apparent maximum sources and sinks during each 0.005 sec. of the activation cycle in a dog with experimentally produced right bundle branch block (RBBB) were studied; the procedure was exactly the same as that used for the normal case described above. The results are schematically presented in Fig. 5. Since intracavitary potentials were not recorded in this experiment, the sites of maximum "sink" are not indicated for the first 0.03 sec. The sequence and localization of the maximum "sources" and "sinks" are those which one would have expected, knowing the process of activation in the dog following RBBB. In the beginning (0.00, 0.005, 0.01, 0.015, 0.02, 0.025, and 0.03 sec., Fig. 5) the areas of maximum positivity are localized in the free wall of the left ventricle. Later the greatest "sources" are located in the anterolateral surface of the free right ventricular wall (0.035, 0.04, 0.045, 0.05, and 0.055 sec., Fig. 5) and the maximum

potential is displaced from right to left. Again the source shifts to its previous location on the right (0.06 sec., Fig. 5). This is a characteristic example of "Gaussian potential" to which we previously referred, since it is impossible to conceive these regions becoming activated twice during a single electrical systole. The first maximum positivity in the right anterior wall (0.035 through 0.055 sec., Fig. 5) is due to the activation of the interventricular septum. The second group of "sources" in the same regions is a result of the activation of the anterior wall proper (0.06, 0.065, 0.07, 0.075, and 0.08 sec.).

At the end of ventricular activation, the sources are located in the pulmonary conus (0.085, 0.09, 0.095, and 0.10 sec., Fig. 5). During the time in which septal and right ventricular activation is occurring, the corresponding sinks are localized in the left ventricle.

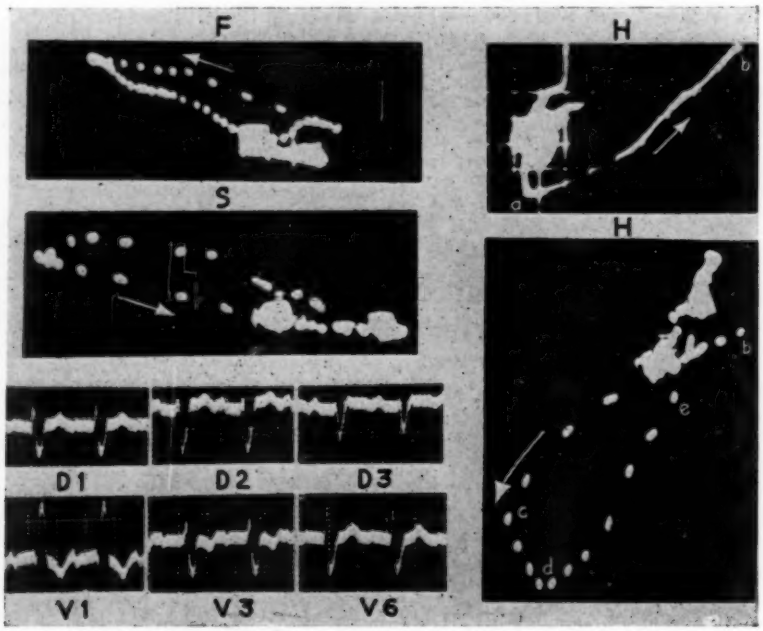

Fig. 7.

The Vectorcardiogram Calculated From the Apparent Maximal Instantaneous Potential Gradient During Experimental RBBB.—Just as we did for the normal case, small sticks which were roughly proportional in magnitude and had the same direction as the vectors determined by the maximum sources and sinks were placed in a small ball of wax. The selected times of the vectors were 0.02, 0.04, 0.06, 0.08, and 0.10 sec., respectively. For the 0.02 sec. vector it was assumed that the maximum sink was in the left ventricular cavity.

The calculated vectorcardiograms (Fig. 6) are very similar to the ones derived by using the cube system electrode placement. The similarity, while striking for the horizontal and sagittal planes, is quite inapparent in the frontal plane. Despite the latter, the rotation in all curves is in exact agreement; moreover, in the case of the horizontal plane the VCG follows approximately the sense of the activation process. In this curve it is easy to delineate the 3 principal portions of the curve: the first, directed toward the left and forward, corresponds to the activation of the free left ventricular wall; the second, showing an abrupt change from left to right, corresponds to septal activation; the third is oriented from front to back and corresponds to the activation of the free right ventricular wall. The concluding portion of the loop, as given by the other 2 curves (frontal and sagittal), runs upward and to the right, just as is found in the terminal sense of the activation process.

Vectorcardiogram and Activation in a Clinical Case of RBBB.—Fig. 7 shows a typical case of RBBB in man. In the curve, 4 main portions can be distinguished. The first (*a*, Fig. 7; the first portion of the horizontal VCG is magnified) corresponds to the activation of the left septal

mass and, like the activation process of this region, is directed toward the right and forward. The second (between *a* and *b*) is directed to the left and backward, as is the activation process of the left ventricle. The third (between *b* and *c*) is directed forward and to the right, corresponding principally to the "jump" of the activation wave going from the left to the right septal mass.[7] The fourth and last portion (*c*, *d*, and *e*) in the horizontal plane corresponds fundamentally to the activation of the free wall of the right ventricle, and possibly with some additional contribution of concluding septal activation.

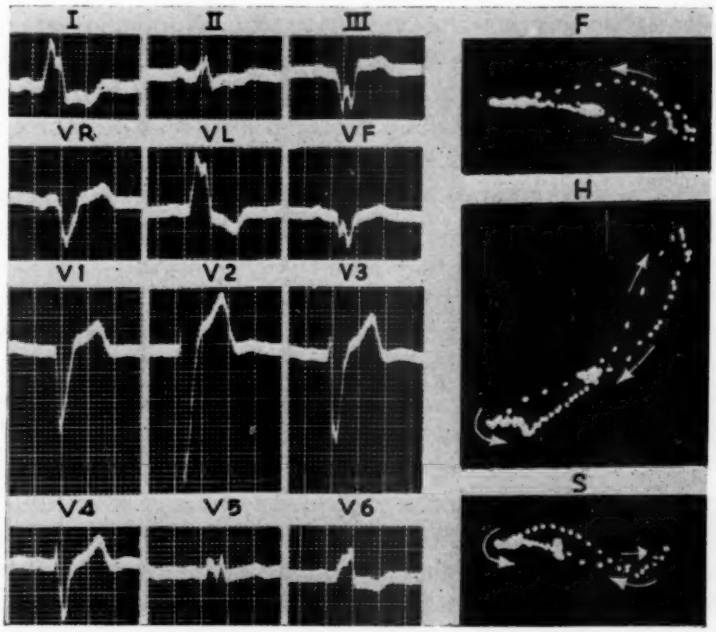

Fig. 8.

Vectorcardiogram and Activation in Left Bundle Branch Block.—(Fig. 8.) The most characteristic curve is seen in the horizontal plane where clockwise rotation occurs. Septal activation is very characteristic in these cases, and, in the main, can account for the clockwise rotation.[5]

DISCUSSION

Though many years have passed, it is still impressive to think that with such exquisitely simple postulates, Einthoven formulated his classical theory. Of the postulates, probably the most important, or at least the one that seems to rest on firmest ground, is the one which allows the totality of electrical charges in the heart to be considered as a dipole. In reality, most serious investigators will allow an analysis based on this construction only if recordings are made at a point farther than a minimal distance. Einthoven himself indicated his awareness of this very important limitation in a series of letters to Frank N. Wilson.[2] Similarly, recent experimental studies confirmed the dipole concept for distant leads and denied the applicability of it when working proximal to the heart.[13] The Stratton theorem gives a mathematical basis for the above-mentioned postulate.

Various studies[14,15] based on the heart proper, and using special models simulating conditions met in the electrical field surrounding the heart, again demonstrate the validity of the dipole concept.

In a thesis by Rinaldi,[16] the author stressed the incorrectness of dealing with vector sums within the heart if the parallelogram law is used; the various vectors are of the fixed variety and not translatable to a common origin. This criticism is valid when working close to or within the heart; mathematically, the restriction is removed when working at a distance. Some time ago this view was contested by one of us (S.-P.) in a personal communication to the French author; the matter was put thus, "It is quite true that we are dealing with fixed vectors which do not lend themselves to the type of vector addition allowed in the parallelogram law. Nevertheless, if we consider the entire cardiac cycle, it can not be denied that there is truly a centroid or center of charges of both maximum negativity and maximum positivity. The vector drawn between the two centroids corresponds to the mean electrical axis. Its magnitude depends upon the sites of the centroids (positive and negative); this vector is not equivalent to the vectorial sum of these main fixed vectors."

In the present experimental work, the sites of maximum positive and negative potentials were located, not for all the cardiac cycle, but rather during successive 0.005 sec. intervals of the activation process. These sites are the locations of greatest positive and negative charge density. For the type of charge distribution likely to be found in the heart, these sites also approximate the centroids of positive and negative charge.

In order to calculate the magnitude and direction of the equivalent dipole at a distance, Stratton[3] spoke of several constants which are contingent upon the prevailing charge distribution. So far as we know, no authors have dealt with these constants as they refer to the heart; for that matter, the charge distribution in the heart is most complex and results in difficulty in knowing the mean path of a deviation. We believe that we have given a partial solution to the problem by determining the maximum source and sink.

By this measurement we know the mean path travelled by the activation wave and also the mean spatial distribution of the charges; this latter fact allows us to approximate the constants of the dipole given by Stratton's theorem.

Undoubtedly, the facts are even more complex than we have indicated in this study; the "apparent" dipole is by no means unique. We encountered instances in which at least 2 "sources" and "sinks" of approximately equal importance were found. These results are due to the fact that, in the dog, right ventricular potentials are of a magnitude equal to or greater than those of the left.

In the normal human heart, a certain simplification is encountered since the right ventricular potentials are small in comparison to those of the left; the probability of encountering several maximum sources for a given sink is quite remote.

It is possible by a mathematical analysis* to show that the components of the dipole, which is equivalent at great distances to the arbitrary charge dis-

*The authors intended to publish, together with this paper, an appendix section in which Dr. Clinton D. Janney studied the derivation of Stratton's theorem, and the components of the equivalent dipole were determined. Through this mathematical study it was possible to demonstrate that "the dipole formed by $+Q$, at $(\overset{+}{x}, \overset{+}{y}, \overset{+}{z})$ and $-Q$ at $(\overset{-}{x}, \overset{-}{y}, \overset{-}{z})$ has a certain uniqueness about it. It is as though all of the actual positive charge were gathered together at the centroid of the positive charge and all of the negative charge were similarly gathered together at the centroid of the negative charge." Because of editorial specifications, however, this appendix section could not be published.

tribution, are identified with the respective components of a dipole formed by concentrating all of the charge at the centroids (centers of gravity) of the negative and positive charges. The direction of the vector that we call "apparent instantaneous maximal potential gradient" is probably much like the axis of this dipole. In favor of this point of view is the small curvature of the wave fronts (Fig. 3). Further experience with intramural exploration will give us better results as we approach the center of gravity of the charges. Another aspect which is the essence of this work is worthy of discussion. We refer now to the recognition via distant recording techniques (vectorcardiogram) of the sense and sequence of the activation process of the heart. In the experimental results obtained from the study of the dog in normal conditions and in bundle branch block, it is seen that a good concordance exists between the activation process and the vectorcardiogram. Also, in clinical vectorcardiography sufficient information is given about both the normal and abnormal bundle branch block activation process. By this we do not mean that any vectorcardiographic curve gives us all the information sought after. Probably the most appropiate for our purposes is the horizontal plane.

In general, we can establish that if the rotation of a given loop is counterclockwise on the horizontal plane, then the activity of the free wall of the left ventricle is predominating. If clockwise rotation is encountered, it must be presumed that the normally powerful potentials of the left ventricle have disappeared (as in myocardial infarction) or have been overridden by even more potent potentials (right ventricular hypertrophy, or septal forces generated during right bundle branch blocks).

It can be stated, in general terms, that we may easily recognize the sequence of ventricular activation through a vectorcardiographic curve if the electrical forces of one ventricle are markedly predominant (isolated ventricular hypertrophy, bundle branch block, etc.). On the other hand, that information will be difficult to achieve if the magnitude of the electrical forces are about the same for both ventricles (biventricular hypertrophy).

SUMMARY

The vectorcardiogram gives valuable information on the sequence of ventricular activation.

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STUDIES ON THE MECHANISM OF VENTRICULAR ACTIVITY. XXI THE ORIGIN OF THE DEPOLARIZATION COMPLEX WITH CLINICAL APPLICATIONS

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A DETAILED analysis of the unipolar complex as recorded from the epicardial surface of the heart and its correlation with potentials from intramural levels of the ventricular wall has not been performed in the past. Because the potentials recorded in a unipolar epicardial lead form important constituent parts of the clinical electrocardiogram, analysis of the genesis of this complex seemed important. Pathologic changes of the surface leads can be attributed to specific lesions only in the light of the origin of the normal complex. The clinical applications of these studies in the diagnosis of myocardial infarctions and other lesions by means of the electrocardiogram are obvious. A loss of forces in the ventricular wall will be expressed in the surface complex only in that part where it is normally represented; that is, the surface complex over a myocardial infarct represents the sum of the negativity of the cavity plus the positivity generated by the normal wall, minus the lost forces. This was stated in general terms by Wilson[1] but not analyzed for its components.

In this study, unipolar leads from the epicardial surface of dogs' hearts were recorded simultaneously with bipolar and unipolar leads within the underlying ventricular walls at 1 mm. intervals of depth. Unipolar recordings were taken at intramural levels in order to study the development of the configuration of the unipolar surface complex. The intrinsic deflection of the intramural bipolar leads indicated the moment of local activation and was correlated in time and polarity with the surface complex. A statistical comparison of the time of occurrence of bipolar and unipolar intrinsic deflections was made in order to evaluate the accuracy of the latter. The apparent speed of the myocardial activation process was calculated from the time of arrival of the activation at different intramural levels on the basis of the intrinsic deflections at these levels.

A new, simple modification of a contiguous bipolar electrode is described. The results obtained were compared with those obtained from dogs with myocardial infarctions after coronary ligation and, in addition, with those obtained from exposed human hearts with myocardial infarctions undergoing chest surgery. The theoretical implications of these correlations on the electrocardiographic diagnosis of myocardial infarctions and other lesions is discussed.

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Aided by grants from the United States Public Health Service, and the L. D. Beaumont Trust Fund.

Received for publication Feb. 28, 1957.

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MATERIAL AND METHODS

A total of 23 mongrel dogs was used in this study. Anesthesia, artificial respiration, and operative exposure of the animal's heart have been described elsewhere.[2] The pericardium was not removed in order to prevent excessive movements of the heart. Pericardial windows were produced by short excisions at the locations under investigation. Apical, mid-ventricular, and basal areas on the anterior surface of the left ventricle were chosen for the placement of the eletrodes. Cotton-tipped, silver-wire electrodes soaked in saline were used for unipolar surface leads. These were sutured on the free border of the pericardial windows and kept in place there. These leads served as time reference for all intramural leads.

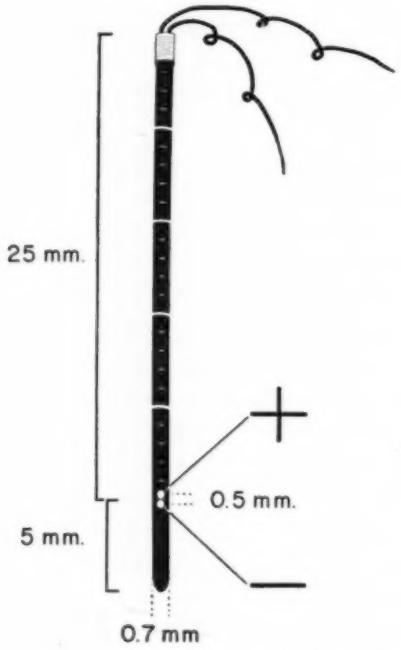


Fig. 1.—Diagram of contiguous bipolar electrode. Leading points are 0.5 mm. apart, with positive pole superior to negative pole. Leading points are placed 5 mm. from tip of electrode to provide stability while most of electrode is withdrawn, recording in outer layers of myocardium.

The plunge electrodes were introduced into the myocardium at right angles to the epicardium in a position as close to the surface electrodes as possible. Records were taken from the cavity first. The plunge electrode was then withdrawn millimeter by millimeter, and tracings were recorded at each position up to the epicardial surface. Before taking bipolar tracings from the plunge electrode, unipolar tracings were recorded from each pole of the bipolar electrode because a difference in pickup between the two poles may produce unrecognized distortions in the bipolar complex.[3] Records were taken only after the unipolar records from both poles of the electrode were observed and showed no artefacts, especially no displacement of the base line between complexes.

"Transmural" bipolar leads were taken in 14 experiments in order to study the relation in time of the beginning of the negativity from the cavity with the beginning of the positivity developed transmurally in connection with the origin of Q waves in unipolar epicardial leads. In these "transmural" leads, a unipolar plunge electrode, as described previously from this laboratory,[2] was placed in the cavity subjacent to the surface electrode. Bipolar records were taken from the two electrodes, with the surface lead as positive pole and the cavity lead as negative pole.

The thickness of the ventricular wall at the site of leading was determined before the plunge electrode was introduced and after it was removed by slowly pushing a hypodermic needle connected with a syringe through the wall until blood could be aspirated from the cavity. At this point, the depth could be read from millimeter markings on the shaft of the needle.

Contiguous Bipolar Plunge Electrodes.—Contiguous bipolar electrodes are designed to exclude extrinsic effects from the leads taken. Distant electrical events influence both leading points in the same fashion and are cancelled out. Only the potential difference between the two poles is recorded. The distance between these should be small in order to restrict the range of recording of the electrode.[4-11]

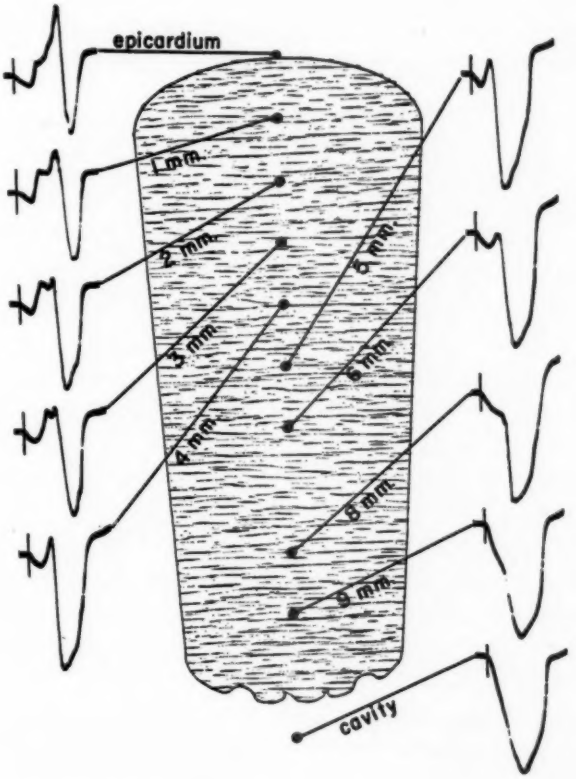


Fig. 2.—Unipolar recordings of Q wave from indicated intramural levels of the myocardium. Common reference time mark. Note that Q wave of surface complex represents remainder of beginning negativity from cavity which can be followed through in all leads.

After trial and error with different types, a modified contiguous bipolar electrode was selected as the most appropriate for the investigation of intramural potentials (Fig. 1). Two insulated silver wires with a diameter of 0.15 mm. are threaded through two small holes drilled in the needle shaft at a distance of 5 mm. from the tip of the needle. The ends are insulated against each other and against the shaft. The distance between the two leading points is 0.5 mm., and the leading surfaces are exactly equal in size, each with an area of 0.0177 $mm.^2$. The shaft of the needle is marked from a point between the two poles up to the base by 1 mm. markings. The position of the leading points at any depth can be read from these markings. The light weight of the needle, less than 1 gram, prevents its slipping out of the myocardium as heavier electrodes tend to do. The obvious advantages of this newly-designed bipolar electrode are its simplicity and cheapness, and the ease of recording from any desired position in the myocardium, with little or no undesired electrode movement.

Recording Equipment.—Two Grass Preamplifiers (Model P 4) with an input impedance of 2 megohms were used together with a dual-beam cathode-ray oscilloscope (Dumont Model 322A). The frequency response was flat from 0.5 to 10,000 c.p.s. Records were taken with a Fairchild Oscillo-Camera. For monitoring, a second dual-beam oscilloscope with a long persistence tube was used (Dumont Model 279). Five inch prints were made from the 35 mm. film in order to study details of the recordings.

Artefacts.—Great care was taken to avoid artefacts which might occur in the recording of intramural complexes. Bounce effects, predepolarization artefacts, and the QRS changes due to injury were described previously.[2] In addition, we found that contiguous bipolar electrodes made of tungsten often produced artefacts, the nature of which was not determined. For this reason silver electrodes were used for this study.

Our technique of recording direct surface and intramural potentials has been improved gradually since our earliest intramural studies in 1951.

RESULTS

With some variations, the unipolar surface complex consisted of QrR'S wave, with a mean duration of 21.3 ± 3.6 msec.

1. *Q Wave.*—The genesis of the Q wave was studied by means of unipolar and transmural bipolar recordings. In unipolar tracings taken from the epicardial surface, Q waves were rarely seen in the area close to the septum. They appeared at about halfway between the septum and the lateral wall. The beginning of the Q wave was simultaneous in all complexes and coincided with the beginning of the QS wave from the left ventricular cavity. The mean Q duration was 4.0 ± 2.1 msec.

When intramural recordings were compared in time with cavity and surface tracings, it was found that the Q wave or initial negativity of surface complexes was derived from the transmitted negativity of the cavity (Fig. 2). This was confirmed by a correlation in time of the beginning of the unipolar cavity and surface complexes with the beginning of "transmural" bipolar tracings. These bipolar recordings can be considered to approximate closely a summation of all the potential differences across the wall.

In locations where the complex from the underlying cavity preceded or was simultaneous with the "transmural" bipolar record, a Q wave was found in the unipolar surface complex. However, with the exception of Base M, in the cases where the "transmural" bipolar recording preceded the cavity complex by 1 msec. or more, the local positive forces apparently cancelled the early negative effect from the cavity, and no Q wave appeared on the surface (Table I).

Similar Q waves were found in unipolar surface leads from a normal human heart which was exposed during chest surgery.*

2. *rR' Wave.*—The r was usually considerably smaller than the R' in the dogs, and in one human case (Fig. 3). Timing of the notches showed that they were inscribed at different times in different locations on the ventricular surface. A shift of the surface electrode of a few millimeters could change the R pattern completely. A second type of upstroke which was recorded less frequently showed no interruption in its ascent (Fig. 3). Its incidence was higher in the apical area than in other areas. Most of these complexes showed a higher amplitude than

*We wish to express our thanks to Doctor Alfred Goldman of the City of Hope Hospital, Duarte, California, for permitting us to take these direct leads.

those with R'.[2] A third type of R had an irregular pattern with two or more notches on the upstroke (Fig. 3). These complexes were seen more frequently in the basal area and averaged the lowest amplitude.

The peak of the R wave, as recorded with high-fidelity equipment, was in most complexes not sharp, but rather smooth (Fig. 3). Three to five msec. after the peak, the intrinsic deflection appeared on the downstroke as a sharp transition from a slow to a fast portion. The duration of this fast portion varied between 1 and 3 msec. Simultaneous unipolar records from the same location on the surface showed that the bipolar intrinsic deflection was inscribed at the same time as the fast portion of the unipolar complex, in most instances toward the end of this unipolar intrinsic deflection.

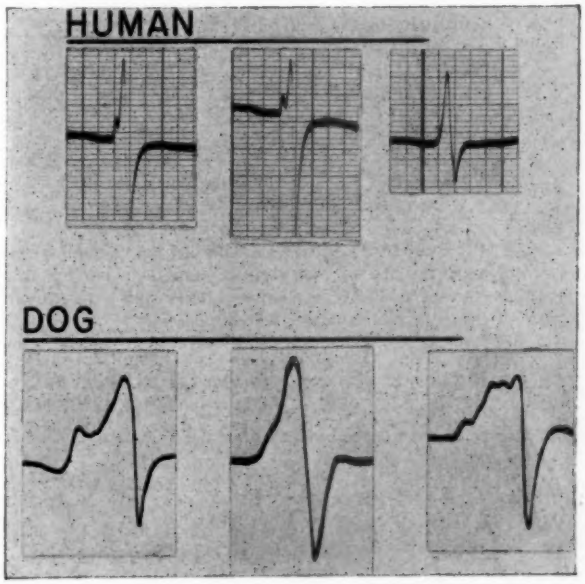


Fig. 3.—Variation in configuration of surface complexes from human and dog hearts. The latter illustrate the rR', simple R, and irregular R described in text. Human records from Sanborn Twin-Beam electrocardiograph; dog records from oscilloscope according to method in text.

In order to study the development of the surface R wave, unipolar and bipolar intramural tracings were recorded simultaneously with the unipolar surface complex. The derivation of the surface R configuration could be traced in the intramural unipolar recordings. The intrinsic deflections of the bipolar tracings indicated the time and the direction of local activation and served as a basis for correlation between the time of activation at different intramural levels and the part of the surface complex corresponding in time to activation processes underneath.

When the plunge electrode was withdrawn from the cavity, and recordings were taken at 1 mm. steps, the first signs of local electrical activity were seen at about 1 mm. from the endocardial surface in the ventricular wall. In the *unipolar recordings* from these subendocardial levels, a sharp, fast portion in the downstroke of the QS wave was observed. This part was, in most instances, preceded by a slur or an embryonic r wave (Fig. 4). A correlation of the measured

depth of the ventricular wall and the levels where the first signs of electrical activity were observed is given in Table II. The mean difference between the two values varied from 0.6 to 1.0 mm.

TABLE I. CORRELATION OF UNIPOLAR CAVITY LEADS AND TRANSMURAL BIPOLAR LEADS

EXPERIMENT NUMBER	COMPLEX WHICH BEGINS EARLIEST	TIME DIFFERENCE	PRESENCE OF SURFACE Q WAVE
Apex K	Cavity	1.8 msec.	Q
Apex L	Transmural	0.2 msec.	Q
Apex M	Simultaneous	0.0 msec.	Q
Apex N	Transmural	1.0 msec.	No Q
Mid K	Transmural	1.2 msec.	No Q
Mid L	Simultaneous	0.0 msec.	Q
Mid M	Transmural	5.8 msec.	No Q
Mid N	Cavity	1.8 msec.	Q
Mid O	Simultaneous	0.0 msec.	Q
Base M	Transmural	0.8 msec.	Q
Base N	Cavity	1.0 msec.	Q
Base O	Cavity	4.6 msec.	Q
Base M	Transmural	2.4 msec.	Q

With one exception (Base M), a Q wave appeared in the unipolar surface complex when the bipolar transmural complex was simultaneous with or less than 1 mm./sec. earlier than the cavity complex. The initial predominance of the cavity negativity was lost when the transmural complex preceded the cavity complex by more than 1 mm., in which case no Q appeared.

TABLE II. CORRELATION OF MEASURED DEPTH OF VENTRICULAR WALL WITH LEVELS WHERE FIRST SIGNS OF ELECTRICAL ACTIVITY WERE OBSERVED

	NUMBER OF EXPERIMENTS	BY ASPIRATION OF BLOOD FROM CAVITY	BY FIRST ELECTRICAL SIGNS IN INTRAMURAL LEADS (See Text)
		Depth of Left Ventricular Wall	
Apex	21	11.8 ± 1.8 mm.	11.2 ± 1.9 mm.
Mid	14	13.6 ± 2.1 mm.	12.6 ± 3.0 mm.
Base	14	16.8 ± 3.0 mm.	16.1 ± 2.6 mm.
		Appearance of First Positive R Wave in Intramural Leads (Depth)	
Apex		8.6 ± 2.3 mm.	
Mid		8.3 ± 2.6 mm.	
Base		10.5 ± 2.9 mm.	

As the electrode was withdrawn, the embryonic r wave grew slightly in size and duration until it crossed the isoelectric line. The mean levels where this was observed are indicated in Table II. The subendocardial QS zone varied from 27 to 39 per cent of the whole thickness of the ventricular wall. The level of transition between embryonic r waves and true R waves seemed quite independent of the location investigated. In the apical, basal, and mid-ventricular region

the first true R waves were seen at a depth of between 8 and 10 mm. The onset of intramural positivity generally was considerably later than that of the surface complex.

The changes in configuration in the inner layers were slight (Fig. 4). The most conspicuous changes in configuration were observed in the outer layers of the ventricular wall. In that portion, the positivity increased considerably. As the electrode approached the epicardial surface, the intramural tracings resembled the epicardial records more closely. The increase in intramural positivity corresponded mainly to the surface R′ in those records where a notch was observed.

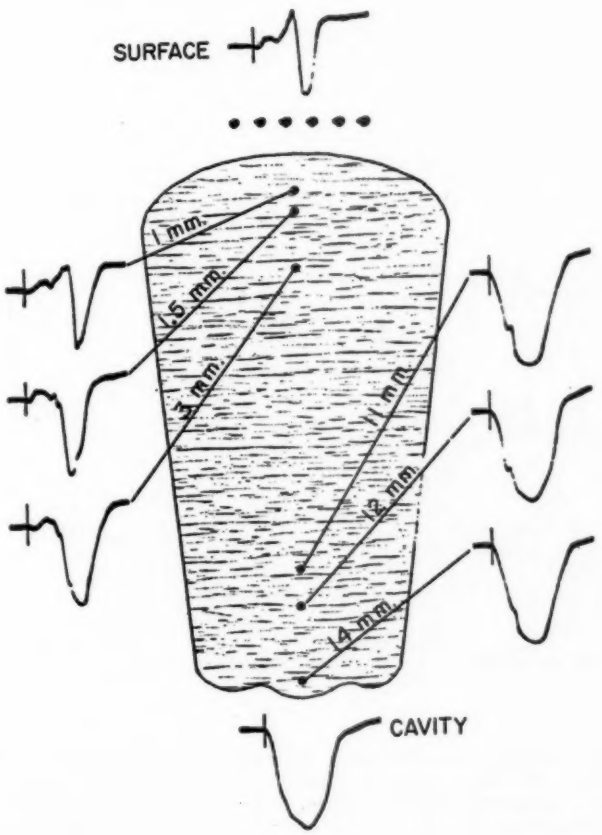


Fig. 4.—Unipolar recordings from specified intramural levels of left ventricle in the dog. Common time reference. At subendocardial levels, a slur or embryonic r wave precedes the intrinsic deflection. Little positivity is developed in these layers. In the outer 3 mm. the R amplitude increases markedly, while changes in the inner 3 mm. are small. Between 11 and 3 mm. a small positive r wave developed.

In surface tracings with a simple R wave, the main rise in positivity in complexes from the subepicardial layers corresponded to the last ⅔ of the surface R. Roughly ⅔ of the total R amplitude of all surface complexes could be attributed to the positive forces generated in the outer layers, sometimes in the outer 3 to 5 mm. (Fig. 4). Only a small part of the first third of the R amplitude could be attributed to the inner layers.

The unipolar surface complex was correlated with contiguous bipolar recordings from the intramural levels by plotting the intrinsic deflection of the bipolar tracings in time against the record from the overlying surface. The polarity of the bipolar records was taken as indication of the direction of activation.

Positive bipolar complexes indicated an activation in endocardial-epicardial direction, and negative complexes, the reverse. Thus, local processes recorded at millimeter intervals could be evaluated roughly as to their contribution to the development of the surface complex, positive bipolar complexes being additive to, and negative complexes being subtractive from, the resulting surface R wave.

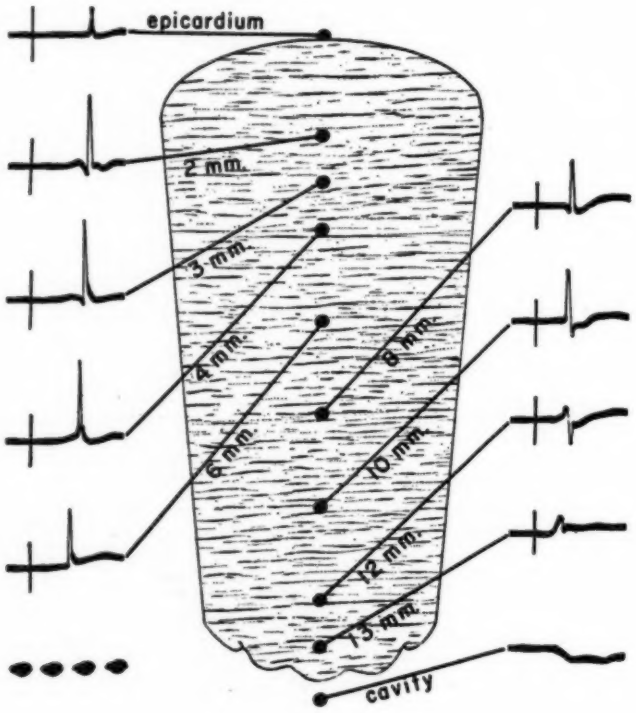


Fig. 5.—Bipolar complexes recorded with contiguous bipolar electrode from specified intramural levels of left ventricle in the dog. Common reference time mark. Note biphasic complex at 12 mm. depth. In most cases, one or two negative complexes were found also in the inner layers. All complexes from outer layers are positive. Time marks are recorded at rate of 120 per second, indicating the short duration of intrinsic deflections. Fast portions of complexes have been retouched for reproduction.

The contiguous bipolar recordings from the subendocardial layers showed fast spikes of a duration of less than 1 msec. (Fig. 5). The polarity was most often positive, but occasionally negative or biphasic. The incidence of negative or biphasic potentials in the deep layers could not be correlated with the depth. They appeared in quite irregular fashion.

When plotted on the simultaneously-taken surface complex, in the majority of cases the earliest forces recorded from the deep layers usually coincided with the last part of the surface r, the following notch, or the beginning of the R′ (Fig. 6). In 38 out of 47 experiments no intramural potentials from the plunge

tract seemed to account for the first 4 to 8 msec. of the surface complex. In the remaining 9 experiments, the intrinsic deflections of the subendocardial layers coincided in time with the beginning of the R wave or, sometimes, with part of the Q wave when a Q wave was recorded on the surface.

The intrinsic deflections from the deep layers usually fell very close together in time and, when plotted on the surface complex, did not reflect a considerable positive amplitude.

In the outer layers, an increase in magnitude of the bipolar complexes was observed which was sometimes 3 times that from the deeper parts. The duration of the fastest portion of the bipolar spike, which occurred usually after the peak of the complex, increased in the outer layers up to a maximal duration of 2 msec. In the outer 5 mm. only positive deflections were observed.

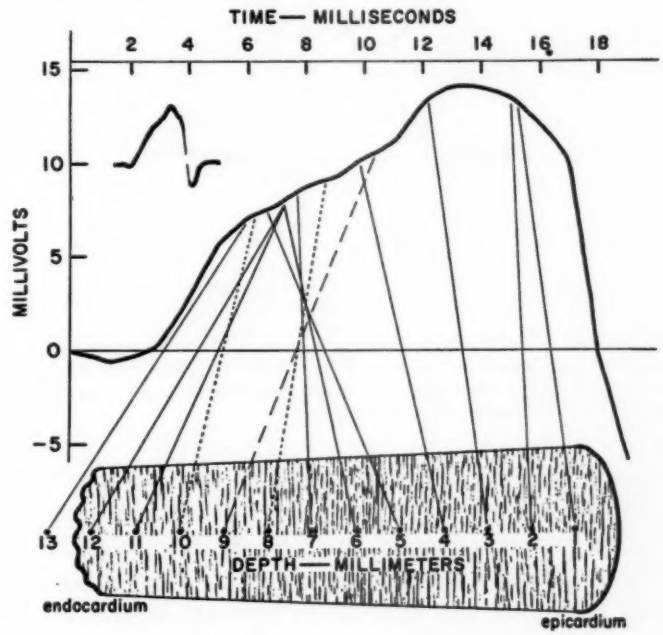


Fig. 6.—Correlation in time of intramural bipolar intrinsic deflections with simultaneously-recorded unipolar surface complex. Polarity of bipolar complex was negative at 10 and 8 mm., and biphasic at 9 mm. Notice the irregular and rapid activation in the deeper layers and the more regular and slower activation in the outer layers. Inset shows actual surface record. No intramural forces from the plunge canal seem to account for the first 6 msec. of the surface complex.

The intrinsic deflections from the outer layers were recorded during the inscription of the epicardial R′ toward the peak of the surface complex, with a concomitant rapid increase in magnitude of this latter tracing (Fig. 6). About ⅔ of the surface positivity was inscribed during the activation of the outer layers. The time intervals between the intrinsic deflections from succeeding points in the subepicardial layers were considerably larger than those in the inner layers. In some of the experiments, the intrinsic deflections of the last few millimeters coincided in time with the intrinsic deflection of the surface complex. Fig. 7 represents diagrammatically the average unipolar surface complex from the left ventricle.

In 13 experiments, the electrode was plunged through a papillary muscle. Here, the earliest intrinsic deflections were found at the same levels as in those without papillary muscle. From this point, the activation seemed to spread in two directions toward the epicardium and endocardium (Fig. 8). The direction of activation in the papillary muscles affects the R amplitude of the surface in a negative sense.

3. *Rate of Intramural Activation.*—From 48 experiments, the time of arrival of intramural activation as indicated by the intrinsic deflections was plotted in 3 groups representing the 3 locations studied (Fig. 8).

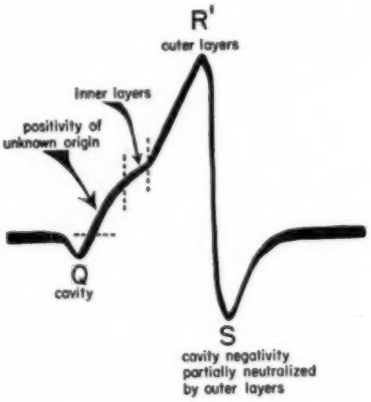


Fig. 7.—Diagram of representative epicardial unipolar complex from left ventricle. Denoted on complex are approximate portions corresponding to potentials from simultaneously-recorded intramural bipolar leads. There was much individual variation.

In the deeper layers the activation showed no regular sequence in time but was extremely rapid. In the outer layers a considerable slowing was observed. The speeds calculated from these measurements are given in Table III. It is obvious from Fig. 8 that speed measurements in the deeper layers in an endocardial-epicardial direction are impossible because of the frequent changes in direction and great rapidity in this region. The duration that the inner layers represent is much shorter than that of the outer layers as shown in Fig. 8.

The mean speed for the activation of the outer layers was 755 ± 268 mm. per second, with a standard error of 38. In the basal region a statistically significant difference in speed was encountered at a depth of 5 mm.; in the apical region, at 3 mm. No significant difference was found when speeds in the outer layers from different regions were compared.

When speed measurements from unipolar and bipolar recordings were compared, the difference was statistically not significant, the value for P being 0.10 to 0.20. The greater standard deviations in calculations from unipolar recordings, however, makes a statistical comparison of these values questionable.

4. *S Wave.*—The S wave recorded at intramural levels changed very little in amplitude up to a level of 6 to 4 mm. Then the loss in S amplitude was quite marked and coincided with the conspicuous gain in amplitude of the R waves (Fig. 9).

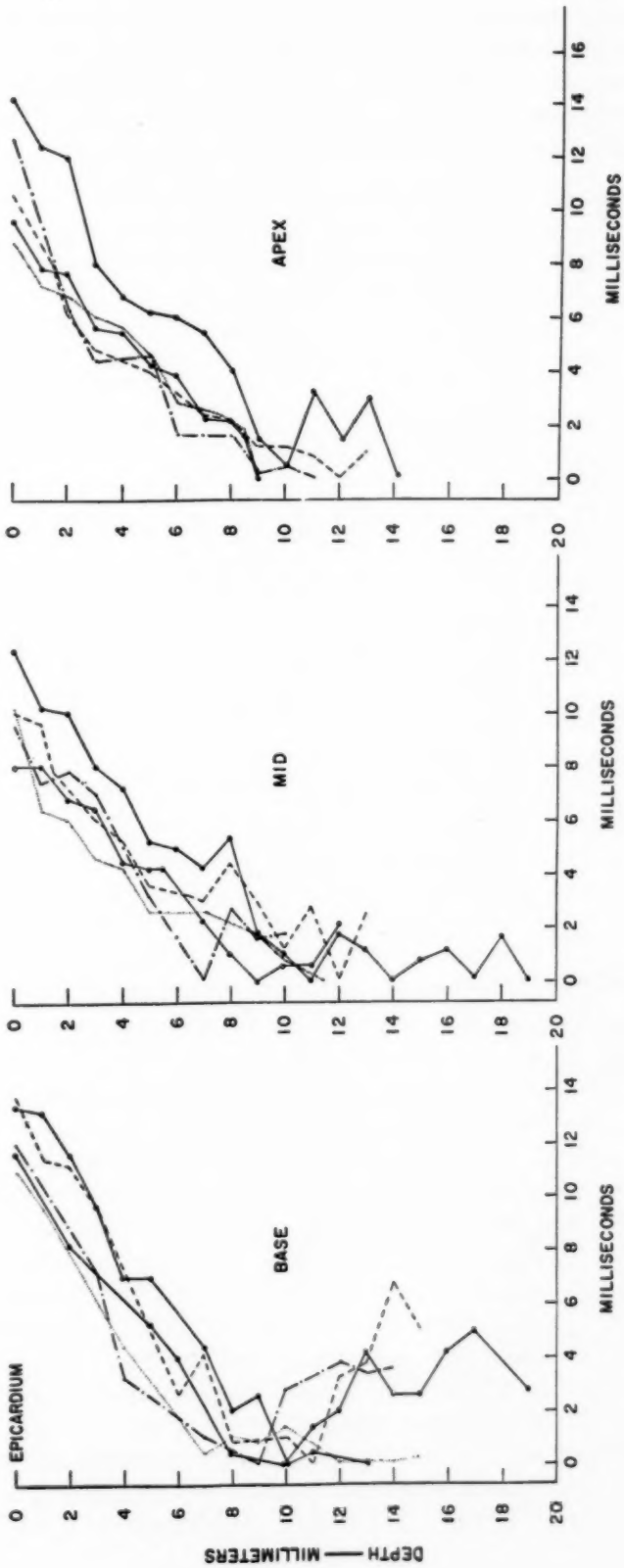


Fig. 8.—Rate of intramural activation. Duration of QR complex. The time of arrival of activation at different depths as indicated by intramural intrinsic deflections at these levels is plotted for 3 locations on the dog's left ventricle. Note the rapid and irregular activation in the inner layers. The rate slows considerably nearer the surface. Bidirectional activation is shown in some of the records from the basal area which were taken in the region of papillary muscle. Note the inner layers about 2 mm.; outer layers around 12 mm.

The S wave of the unipolar surface complex coincided in time with the last part of the QS wave recorded from the underlying cavity (Fig. 9).

In a few experiments, the activation of the outer few millimeters coincided in time with the inscription of the first part of the surface S wave. Positive forces could thus be demonstrated directly opposing the S negativity.

TABLE III

	APEX		MID		BASE	
	NO. OF EXPER.	SPEED	NO. OF EXPER.	SPEED	NO. OF EXPER.	SPEED
Speed of Intramural Activation						
3-0 mm.	20	776 ± 292 mm./sec. S.E. 65	14	884 ± 525 mm./sec. S.E. 140	14	791 ± 336 mm./sec. S.E. 89
5-3 mm.	20	1190 ± 748 mm./sec. S.E. 167	13	857 ± 415 mm./sec. S.E. 115	14	645 ± 219 mm./sec. S.E. 58
7-5 mm.		Not measurable	9	1521 ± 892 mm./sec. S.E. 297	12	924 ± 288 mm./sec. S.E. 83
9-7 mm.		Not measurable		Not measurable	10	1107 ± 408 mm./sec. S.E. 129
5-0 mm.		Not measurable	14	793 ± 303 mm./sec. S.E. 81	14	688 ± 201 mm./sec. S.E. 53

		NO. OF EXPER.		S.E.
Speed in the Outer Layers				
Apex Mid Base	3-0 mm. 5-0 mm. 5-0 mm.	48	(Total) 755 ± 268 mm./sec.	38

		t	P
Correlations			
Apex Apex	3-0 mm. 5-3 mm.	2.32	0.02–0.05
Base Base	5-0 mm. 7-5 mm.	2.40	0.02–0.05

Significant Change in Speed	
Apex	Between 3 and 5 mm.
Base	Between 5 and 7 mm.

In the experiments in which a papillary muscle was studied the S wave showed the greatest amplitude in the center of the spread of activation, becoming smaller toward cavity and epicardium.

DISCUSSION

1. *Q Wave.*—A Q wave preceding the R was found in more than half of our records, mainly those from the lateral wall region. The beginning of this wave in all the records was inscribed simultaneously with the beginning of the QS from the cavity. As was shown by the comparison of cavity leads and intramural bipolar leads from cavity and surface, a Q wave was found on the surface only when the transmural positivity started at the same time or later than the negative complex from the cavity.

The more frequent occurrence of Q waves on the lateral wall facing the septum suggests a septal contribution for this deflection, although our studies were not conclusive in this regard. The relatively late depolarization of the lateral wall with a late development of positivity in this region explains the persistence of an initial negative wave. It can be considered as a remainder of the negativity of the cavity transmitted to the surface.

2. *rR′ Wave.*—The R wave of unipolar surface recordings has been described usually as a straight upstroke. With high-fidelity recording, however, more details can be observed.[4,13] In the order of their frequency of occurrence, 3 types of upstroke were observed in dogs and human beings[21]: *the rR′*, *the simple R*, and *the irregular type* with several notches. Because the configuration may vary from one surface location to another close by, it is suggested that the notches in the upstroke arise from peculiarities of the activation in the vicinity of the leading electrode, the exact nature of which is unknown. Gilson[13] and Schaefer[4] suggested that they may be due to papillary muscles and trabeculae carneae in which a different general direction of activation occur, and/or to irregularities of the activation process in the inner half of the wall.

When the development of the R wave configuration was followed in *unipolar intramural tracings*, it was found that in the deep layers of the ventricular wall a slur or an embryonic r wave appeared on the downstroke of the QS complex. The positivity developed in this region was not strong enough to overcome the negativity transmitted from the cavity. This pattern changed only at midventricular levels when a positive R wave appeared. From this level to the epicardial surface, the R wave grew in size and duration, as described previously from this laboratory.[2] The main rise of the R wave took place in the outer 4 to 5 mm., and the subepicardial tracings closely resembled the surface complex.

An analysis of *contiguous bipolar recordings* from the deeper layers revealed a very intricate situation. Although the majority of the bipolar complexes were positive, indicating an activation in an endocardial-epicardial direction, negative or biphasic tracings were observed at irregular intervals. This indicates that the activation did not travel in a straight course toward the epicardium. The local activation at one position could be later or earlier than that 1 mm. distant, according to the timing of the intrinsic deflections. Greater shifts in time were accompanied by a corresponding reversal in polarity. With smaller time shifts,

this relation did not always hold true. This indicates that depolarization passed the electrode frequently in an oblique direction, because a close correspondence between direction and polarity can be expected only in the lead axis. According to these findings, the subendocardial activation follows an irregular pattern in which the fibers may be stimulated from many directions without the formation of a well-defined activation front. As a consequence, a considerable part of the

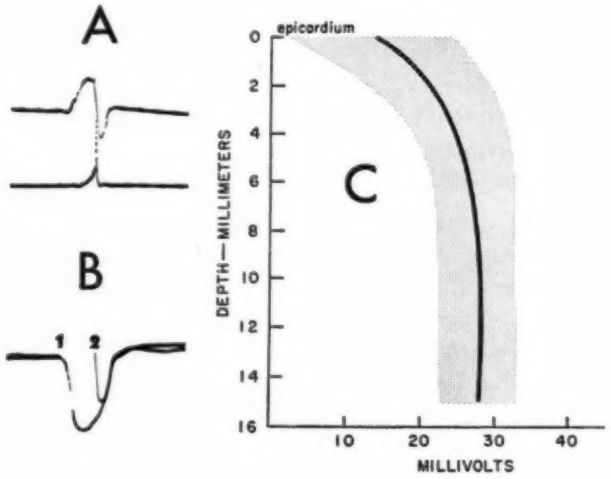


Fig. 9.—S wave. *A*, **Unipolar surface complex over simultaneously-recorded bipolar complex from 2 mm. depth showing that positive forces in the outer layers contribute to the decrease in S amplitude in these layers. In** *B*, *1* **represents the QS wave from the cavity and** *2* **the S wave from the simultaneously-recorded surface complex. Note that the upstroke of these two waves is simultaneous.** *C*, **S amplitude in unipolar tracings from cavity to surface. Solid line is mean; shaded area, range. The S amplitude decreases mainly in the outer layers.**

electrical forces generated in this zone are cancelled out by others opposite in direction. This situation is well illustrated by a study of the time of arrival of activation in the deep layers in Figs. 6 and 8. The forces generated are predominantly positive, but cancellation of forces and the lack of a regular endocardial-epicardial activation front prevent the reflection of any considerable positivity on the epicardial surface.

The diffuse branching of Purkinje fibers in the subendocardium may be the cause of the irregular patterns, as suggested previously from this laboratory and by others.[2,5,8,11,15,16] Polarity reversal phenomena in a transition zone between inner and outer layers as described by Durrer,[16] in 1954, were not observed. More recently, Durrer has obtained results similar to ours.[17]

In the outer layers the events are much simpler and easier to understand. The bipolar complexes were always positive with a greater amplitude and an increased time delay between adjacent recording positions. This constant positive polarity indicated that the activation in this case followed a regular sequence at a relatively slow rate. In the outer layers, no potentials are lost by cancellations, and the depolarization forces exert their full influence on the unipolar epicardial leads.

In order to study the influence of the electrical forces generated in the ventricular wall on the rR′ wave of the unipolar surface complex, a correlation in time between intrinsic deflections from intramural levels and the surface complex was performed (Fig. 6). It was striking that in the majority of these experiments, no forces from a perpendicular axis underneath the surface electrode seemed to account for the first 4 to 8 msec. of the surface complex, regardless of whether this complex showed an initial Q or an initial R wave. In only 9 out of

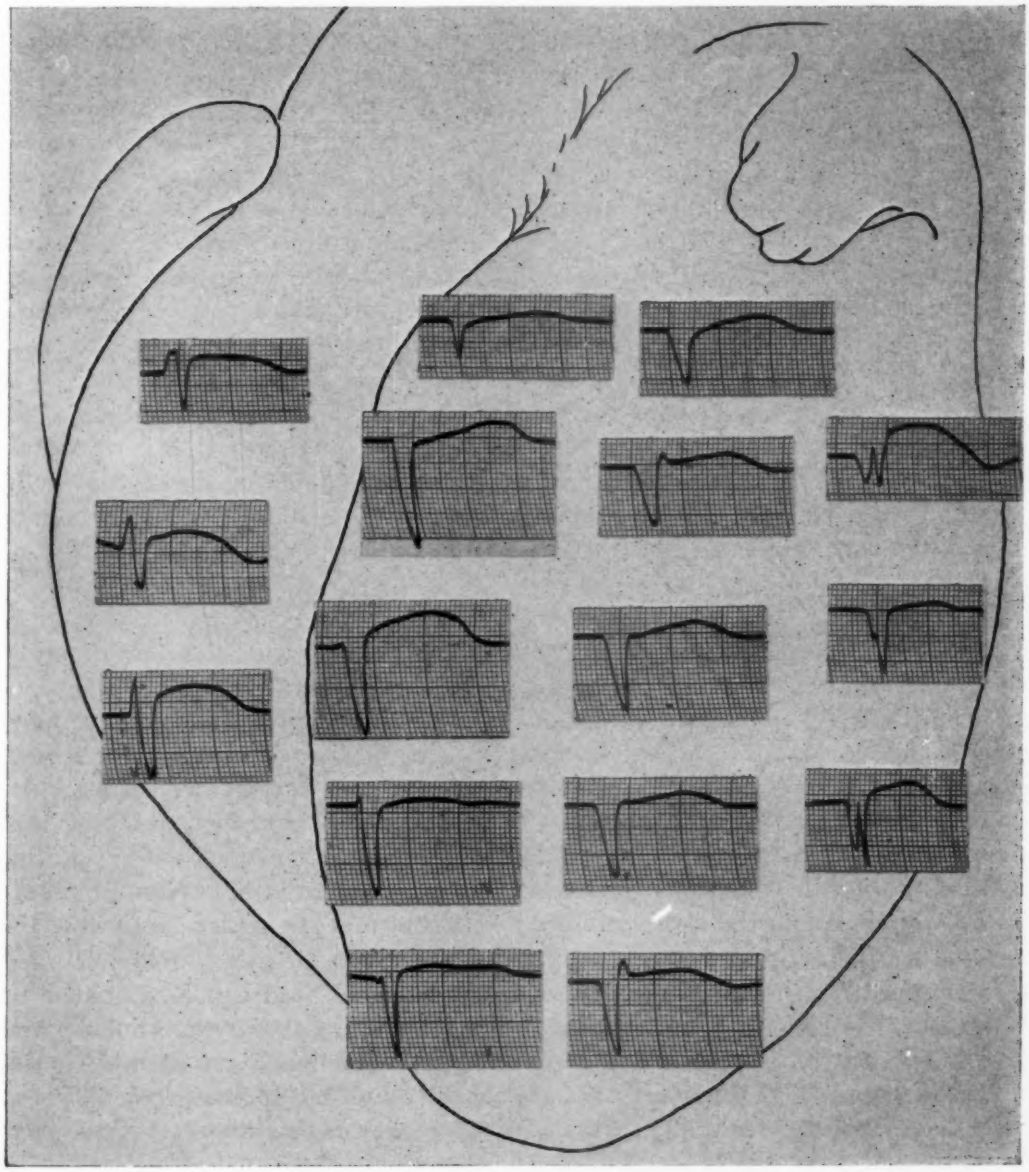


Fig. 10.—Direct-writer recordings taken over the surface of a dog's heart with myocardial infarction due to ligation of a coronary artery. Pure QS waves are seen in some complexes, rS waves in others close by. See text.

47 experiments did intrinsic deflections from the deep parts of the wall coincide in time with the first parts of the surface complexes.

What, then, is the source of the positive electrical forces which account for the beginning of the surface R wave? Potentials from distant parts of the heart, like the septum or right ventricle, cannot contribute to the initial positivity of the surface R because these forces are directed predominantly away from the free wall of the left ventricle. Without conclusive evidence from the present studies, the results of former studies in this laboratory[18,19] on small myocardial infarctions with QS waves have led us to the following assumption. In myocardial infarctions with patchy or complete necrosis of a region of the ventricular wall, pure QS waves are recorded over infarcted areas, even small ones. If we assume that the early positive forces came from a considerable distance, an initial R of low amplitude should still be recorded over the infarction. The finding of pure QS waves, however, leads to the conclusion that the positive forces responsible for the first 4 to 8 msec. of the surface complex originate in close vicinity to the surface electrode. They are not recorded along the perpendicular course of the plunge electrode, but they are recorded by the unipolar surface electrode, due to the characteristics of this lead in subtending a large angle as range of recording. Further evidence for this assumption will be discussed in connection with the clinical applications.

Only about ⅓ or less of the total surface positivity was recorded simultaneously with the activation of the subendocardium, while the forces from the outer layers, when plotted on the unipolar surface complex, showed greater time intervals with a concomitant conspicuous increase in positivity. Thus, the major part of the surface positivity was generated in the outer parts of the ventricular wall (Figs. 6 and 7).

3. *Rate of Intramural Activation.*—Speed measurements are valid only if made in the exact direction of activation. This precludes all determinations in the deeper layers of the wall, since activation there does not necessarily follow an endocardial-epicardial direction. From the findings in this part of the wall, determinations with the present methods of investigation are open to question. Measurements in the more regularly activated outer layers are correct only under the same conditions. Durrer[20] found that the advancing front does not deviate more than 5 to 10 degrees from a perpendicular endocardial-epicardial axis in the outer layers. The front itself, however, was described as having bulges, which would explain the somewhat irregular pattern of the surface activation.

Under these circumstances, we assume these measurements to be of "apparent speed," although the deviation from the true speed can be assumed to be small. The mean speed in the outer layers according to our experiments was 755 ± 268 mm./sec., which lies between the figures previously reported by Lewis and Rothschild[12] and Schaefer.[4] Speeds for the outer half of the left ventricular wall, using unipolar recordings previously reported from this laboratory,[2] were too slow, ranging from 250 to 500 mm./sec.

It was interesting to note that a significant difference in speed was found at the apex after passing a 3 mm. limit of depth, and at the base at 5 mm. Since only two kinds of conduction, that by Purkinje fibers and that by muscle fibers,

are known at present, one might consider a spread of Purkinje terminals up to this limit. This would be the most likely explanation of the significant change in speed.

4. *S Wave.*—The conspicuous decrease in the magnitude of the S wave in the outer layers was concomitant with the main rise in positivity of the R wave. The strong positive forces generated in the outer layers were able to overcome more of the negativity originating from the cavity.

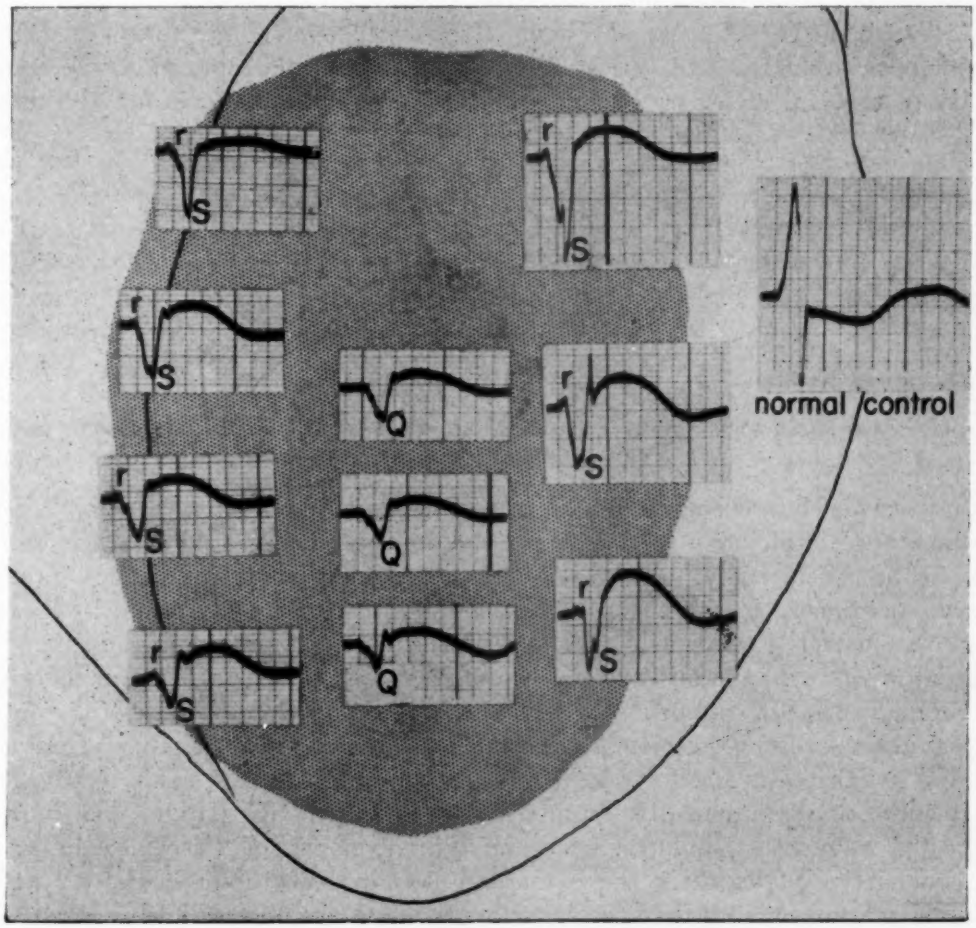


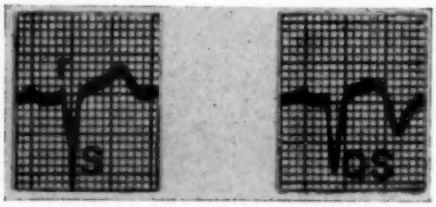
Fig. 11.—Direct leads taken from exposed human heart over myocardial infarction (shaded area). Note QS waves over center of infarct and rS waves over periphery.

In a few experiments, activity from the outermost millimeters was observed almost up to the nadir of the S (Fig. 9). The S wave of the unipolar surface complex represents the remaining unopposed cavity negativity. The balance of positivity and negativity as expressed in the RS ratio of the unipolar surface complex leads to an understanding of the pathologic changes of these waves. A loss of positive forces will be accompanied usually by a decrease of the surface R concomitant with an increase in amplitude of the S wave, a frequent finding in tracings over myocardial lesions.

CLINICAL APPLICATIONS

In the present study, the relationship of the unipolar surface complex with the electrical forces generated in the ventricular wall underneath was studied. This study confirms, with minor modifications, previous work from this laboratory.

If conditions in the human heart are similar to those in the dog, as suggested by the similarity in epicardial leads and by observations of intramural complexes in the human heart,[21] we may assume from the foregoing results that major QRS changes are the consequence of lesions of the outer layers. With the loss of the major positive forces exercised in an endocardial-epicardial direction, the negativity of the underlying cavity predominates, and QS complexes are recorded.



A. *B.*

Fig. 12.—Chest leads from patient with myocardial infarction. *A*, Shows initial r followed by deep S. *B*, Shows pure QS wave. See text.

In myocardial infarctions, a loss of potentials from the outer layers only a few millimeters in thickness may conceivably decrease the R and increase the S amplitude considerably. An rS complex is recorded in such instances, as was shown previously in dogs with experimental myocardial infarction.[19] It was also demonstrated previously that experimental lesions located in the subendocardial layers with the outer layers completely normal had little or no effect on the configuration of the surface complex.[22] A partial or complete loss of the outer layers in a very limited region is sufficient for the strong negative forces from the cavity to take over and for pure QS waves to be recorded.[19] This is true not only with complete tissue death, but also with infarcts of the patchytype (mural-type QS waves).[19] Similarly, widespread involvement of the epicardium, as in constrictive pericarditis, shows marked electrocardiographic changes,[23] while extensive lesions confined to the inner layers, such as endocardial fibroelastosis, may be associated with a normal QRS complex.[24]

A new finding with important clinical implications was that no forces in a perpendicular endocardial-epicardial direction seemed to account for the first 4 to 8 msec. of the surface r wave in 80 per cent of our experiments. Because this positive part disappears even over small infarcted areas,[18,19] it was concluded that this positivity presumably arose from regions in the left ventricle in close proximity to the part under investigation. A review of experimental data gained in human beings and dogs gave further support to this assumption.

A study of records from dogs after coronary ligation showed rS complexes in a great number of cases when leads were taken from the border of the infarct (Fig. 10). The same was true in a patient with anteroseptal myocardial infarc-

tion. The direct leads taken from the exposed heart showed QS waves in the center of the infarct and rS waves in the periphery of the lesion (Fig. 11). From the experimental data obtained in this study, it is suggested that in these cases the electrode was in a position where the outer parts of the ventricular wall had undergone partial or complete necrosis. Viable tissue from adjacent parts, however, contributed enough positive potentials to give origin to a small initial r wave. This r wave at the border of infarctions supports our thesis about its origin in a vicinity close to the exploring electrode. The same observations were made in chest leads from patients with myocardial infarctions (Fig. 12), but one must be careful in drawing conclusions about precordial leads on the basis of results from epicardial leads.

The reciprocal relationship of the amplitude of R and S waves observed in the study of their increase or decrease in the outer layers of the ventricular wall may be an additional clue for the diagnosis of myocardial lesions. A decrease in the size of the R wave may give rise to an increased amplitude of the S wave because the loss of positive forces reveals more of the cavity negativity. The previously published data on dogs with coronary ligations[19,21,22,25] are in full agreement with the RS relations as obtained in this study.

SUMMARY AND CONCLUSIONS

1. The genesis of the unipolar depolarization complex from the surface of the left ventricle has been studied by means of intramural unipolar and bipolar records from the underlying myocardial wall in 47 experiments on 23 dogs and in 1 human case.

2. The derivation of the configuration of the surface complex could be traced in the intramural unipolar recordings. The relative time of activation at different intramural levels and the part of the surface complex corresponding in time to activation processes underneath were determined from intrinsic deflections of the bipolar intramural tracings. A new modification of a bipolar intramural electrode is described.

3. With some variations, the unipolar surface complex consisted of a QrR′S wave. Its mean duration was 21.3 ± 3.6 msec.

4. The Q wave, or initial negativity of surface complexes, appeared in over ½ of the records, had a mean duration of 4.0 ± 2.1 msec., and was found to be derived from the transmitted negativity of the cavity.

5. The subendocardial QS zone varied from 27 to 39 per cent of the whole thickness of the ventricular wall. The first positive R waves were seen at a depth of between 8 and 10 mm. About ⅔ of the total R amplitude of all surface complexes could be attributed to the positive forces generated in the outer layers. Only part of the first third of R amplitude could be attributed to the inner layers.

6. The earliest forces recorded from the deep layers usually coincided with the last part of the surface r, the following notch, or the beginning of R′. In 38 of 47 experiments, no intramural potentials from the plunge tract seemed to account for the first 4 to 8 msec. of the surface complex. Positive forces responsible for this early portion are thought to originate in close vicinity to the surface electrode, i.e., adjacent regions of the left ventricle and possibly, to some extent, the subendocardial region.

7. The S wave of the unipolar surface complex was found to represent the remaining unopposed cavity negativity after neutralization of much of the cavity negativity, largely by positive forces in the outer layers.

8. Activation in the subendocardial layers followed an irregular pattern and was very rapid, while activation in the outer layers followed a regular sequence at a relatively slow rate.

9. The clinical applications of these studies are discussed in relation to the positive forces lost due to myocardial disease.

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SIMPLE METHODS FOR RECORDING INTRACARDIAC ELECTROCARDIOGRAMS AND PHONOCARDIOGRAMS DURING LEFT OR RIGHT HEART CATHETERIZATION

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INTRACARDIAC electrocardiography was first studied in open chest experiments by Lewis.[1] The first intracardiac electrocardiograms in closed chest experiments were recorded by one of the authors and his co-workers.[2] Clinical studies by means of right and left heart catheterization have been done by several authors.[3-6] All the above-mentioned tracings were recorded by using specially constructed catheters having a tip electrode and a wire passing through the catheter. Because routine application was difficult, a new technique has been studied which simplifies the recording of these tracings.*

Intracardiac phonocardiography was first attempted by Soulié[7] with a tiny piezoelectric microphone applied to the tip of a catheter. A second attempt was made by Yamakawa and associates.[8] They used a small metal stick attached to the tip of a catheter and placed in an electric circuit which used the body as a pole. A third attempt was presented by Lewis and associates,[9] who used a hollow cylinder of piezoelectric ceramic at the catheter tip for picking up sound vibrations.† All the above-mentioned techniques required special catheters and were of difficult routine application because of several practical disadvantages.

Pressure tracings recorded during catheterization in cases of pulmonic stenosis or interventricular septal defect frequently reveal vibrations which coincide in time with those recorded by microphones applied over the chest wall. This indicates that the fluid within the catheter is able to transmit vibrations to pressure transducers. This observation was the starting point of a new study.

METHODS

Catheterization was made according to accepted procedures. Catheter Nos. 5, 6, 7, or 8 were used for the right heart. A polyethylene catheter size PE 50 was used for the left heart.

Intracardiac Electrocardiography.—Both types of catheters should be made of insulating material. Therefore, electric currents can be conducted from the tip to the end of a catheter if

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This study was made during the tenure of a Teaching Grant of the National Heart Institute, U.S.P.H.S., and with the help of grants from the Chicago Heart Association, and the Lasdon Foundation of New York.

Received for publication April 1, 1957.

*After this paper had been submitted for publication, our attention was called to two studies of intracardiac electrocardiography using normal saline. They were published by Kisch and associates,[11] and by Hellerstein and associates.[12] These authors found smaller potentials[12] and frequent A.C. interference.[11] A 5 per cent saline solution, used by us, nearly completely prevents these disadvantages.

†A fourth attempt was presented to the New York Heart Association (April, 1957) by Moscovitz, Donoso, Gelb, and Welkowitz. They used a ceramic piezoelectric microphone.

the saline solution filling the catheters is used as an electric conductor instead of a wire. For better conduction, the catheter should be filled by means of a syringe with 0.5 c.c. (left heart) or 1 c.c. (right heart) of 5 per cent sterile saline solution with 10 per cent heparin. If the limbs of a subject are connected with the usual electrodes and the wire of an exploring electrode (chest lead wire) is connected with the stopcock of the strain gauge, a "unipolar" intracardiac lead can be recorded by using Wilson's central terminal. The only difference from the previously used technique is the substitution of the conducting fluid for an intracardiac electrode, thus obviating the need for special catheters. It is suggested to call the unipolar leads after the four cardiac chambers: V-RA, V-RV, V-LA, and V-LV. Recording can be done by using any type of electrocardiograph. The authors employed the ECG channel of a cathode-ray oscilloscope. The tracing was photographed on sensitive film from the oscilloscope, together with other tracings.

Intracardiac Phonocardiography.—The catheter placed in any of the cardiac chambers or large vessels contains a column of fluid which reaches from the heart to a strain gauge or electromanometer. Water is a good conductor of sound vibrations (1,500 meters per second). Therefore, it is possible to pick up the latter from the end of the catheter instead of from its tip. Our first series of experiments used a Sanborn electromanometer (121 B model) and a variable band-pass Krohn-Hite filter.* The electric output of the manometer was passed through the filter by using bands of 60 to 110, or 60 to 250, and then fed into the input of the ECG amplifier of a Sanborn Twin-Beam. In a second series of experiments, we made use of specially-built electronic equipment.† This consisted of a six-channel cathode-ray oscilloscope with photographic recording. One of the channels was used in conjunction with a strain gauge‡ of high frequency response for pressure recording. A short cable connected this channel to another channel for sound recording. The vibrations of sonic frequency were obtained from the strain gauge through triple electric differentiation and with the use of two variable band-pass filters. A single section of the RC type provides differentiation for signals with frequency below 100 cycles which are fed to a "linear" amplifier. Upon being fed to an amplifier with "stethoscopic" characteristics, the signals receive a second differentiation; fed further to an amplifier with special filters, they receive a third differentiation. Signals having frequencies higher than 100 per second pass undifferentiated but amplified. The output of the "differentiators" increases linearly with increasing frequencies up to 100 cycles per second, and then gradually flattens off to give constant output. The final output is obtained through the use of a low-pass and a high-pass filter. Both cause the signals to decrease at a rate of 12 decibels per octave, at frequencies respectively below and above those selected by the switches. Bands of 60 to 110 or 60 to 250 were used. The P 23 D gauge has a flat response up to 70 cycles per second, and then increases its frequency response until resonance occurs at 280 per second.[10] Therefore, accurate reproduction of vibrations between 0 and 250 is obtained. The heart sounds from inside the heart can be checked before recording by using either an oscilloscope (visual) or an audiophone (auditory). With this technique, the only new device added to the instrumentation is a second circuit, connected to that of the strain gauge by means of a short cable. It is self-understood that, as in routine phonocardiography, a correct tracing can be obtained only by using photographic recording.

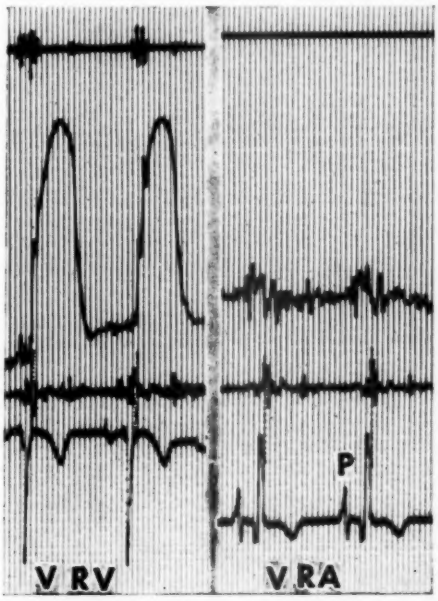
RESULTS

Electrocardiography.—The tracings recorded inside the heart exhibited the typical features of intracardiac electrocardiograms: high, diphasic P wave in the right atrium, rS complex in the right ventricle, and QS complex in the left ventricle (Figs. 1, 3, 4, 5). Whenever the catheter tip touched the ventricular wall, a significant elevation of S-T was noticed. Slight withdrawal of the catheter led to immediate disappearance of this pattern. Occasionally, slight variations of the complexes were noted in the ventricles. This was explained as being due to flopping of the catheter tip in the ventricular cavity. The recording of intra-

*Supplied by the Krohn-Hite Company, Boston, Mass.
†Built by "Electronics for Medicine", White Plains, N. Y.
‡Statham P 23 D.

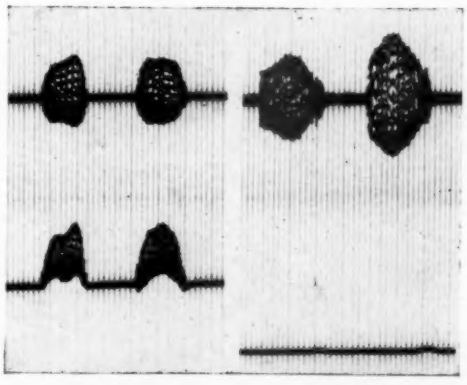
cardiac electrocardiograms together with pressure tracings and fluoroscopy, were found helpful in the routine identification of the various chambers.

Phonocardiography.—In vitro experiments proved that sounds applied to water in an open container were recorded from the strain gauge while only minimal changes in pressure took place. Other experiments were made with the catheter-gauge system full of air. A musical note created with the mouth at the tip of the catheter was transmitted to the gauge, differentiated, filtered, and recorded.



A. *B.*

Fig. 1.—Right heart tracings recorded in a case of pulmonary hypertension during right heart catheterization. Film speed: 22 mm. per second. *A*, Right ventricle. From above: intracardiac heart sounds (range 60 to 110); intracardiac pressure pulse; external phonocardiogram; intracardiac electrocardiogram (V-RV). *B*, Right atrium. From above: intracardiac pressure pulse; external phonocardiogram; intracardiac electrocardiogram (V-RA).



A. *B.*

Fig. 2.—Vibrations recorded from the strain gauge circuit and from its differentiated and filtered derivation. Low-pitched notes generated with the mouth at the tip of a No. 8 catheter connected with a P 23 D gauge. Tracings recorded at 25 mm. per second film speed. *A*, High amplification on gauge, low amplification on sound circuit. *B*, Low amplification on gauge, high amplification on sound circuit.

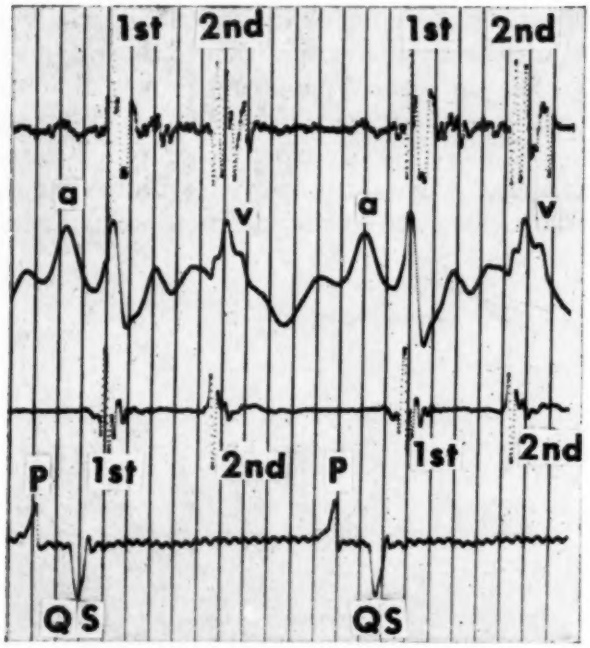


Fig. 3.—Tracings recorded in the left atrium of a normal dog. Film speed: 100 mm. per second. From above: intracardiac sounds (range 60 to 250); intracardiac pressure pulse; external phonocardiogram; intracardiac electrocardiogram (V-LA).

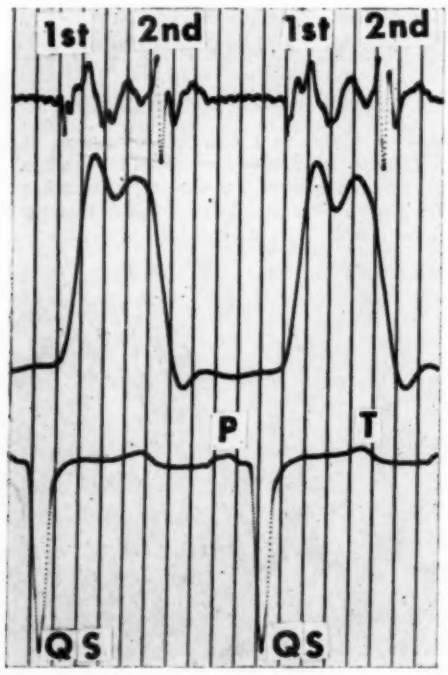


Fig. 4.—Tracings recorded in the left ventricle of a normal dog. Film speed 100 mm. per second. From above: intracardiac sounds (range 60 to 110); intracardiac pressure pulse; intracardiac electrocardiogram (V-LV).

Low-pitched notes were recorded as vibrations of greater magnitude. High amplification on the pressure channel and low amplification on the sound channel were revealed by the existence of vibrations superimposed on the pressure pulse, while a tracing devoided of low frequency components recorded in the sound channel (Fig. 2,*A*). Low amplification on the pressure channel and high amplification of the sound channel, on the contrary, was revealed by a smooth pressure pulse and by a typical sound tracing in the sound channel (Fig. 2,*B*). Experiments performed in animals proved that:

1. Sounds and murmurs are recorded from the heart (Figs. 3, and 4). There is a minimal delay (0.01 to 0.02 sec.) of the left heart sounds over those recorded at the apex (effect of filters, plus transmission through fluid), while a greater delay (0.03 to 0.04) occurs between right heart sounds and apical sounds (slight asynchronism of the two ventricles).
2. Diastolic sounds and systolic or diastolic murmurs are well recorded.
3. The magnitude of the two main heart sounds decreases in the following order: left ventricle, right ventricle, ascending aorta and pulmonary artery, left atrium, right atrium.
4. Respiration does not interfere with intracardiac phonocardiography. (Respiratory vibrations do not reach the cardiac chambers.)
5. The recorded vibrations are not due to hitting of the catheter by the cardiac valves.

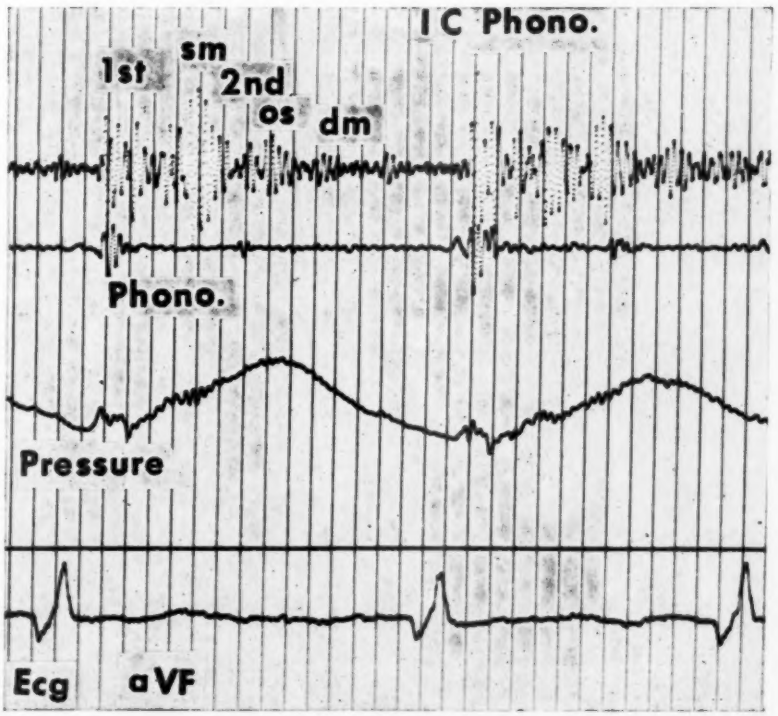


Fig. 5.—Tracings recorded within the left atrium of a patient with severe mitral stenosis and moderate mitral insufficiency. From above: intracardiac phonocardiogram (range 60 to 110); external phonocardiogram; pressure pulse; ECG (aVF).

6. The thin polyethylene catheter used in left heart catheterization has a slight damping effect which, however, does not prevent obtaining a good tracing. Special care should be used in frequently washing this catheter.

Clinical observations are being made through both right and left heart catheterization and will be presented later. A tracing of the left ventricular pressure pulse, sound vibrations, and electrocardiogram in a case of mitral stenosis is presented here as an example of the data supplied by the new method (Fig. 5).

SUMMARY

Two new techniques are presented for use in routine cardiac catheterization or in special studies on the heart.

1. *Intracardiac electrocardiography* is done by using a column of 5 per cent saline solution with 10 per cent heparin within the catheter as an "exploring" electrode. The "chest" wire is connected with a metal outlet of the strain gauge.

2. *Intracardiac phonocardiography* is done by using the column of normal saline or glucose solution within the catheter as the carrier of sound waves. The electric output of the strain gauge is differentiated, amplified, and filtered, and is recorded by a phonocardiograph. Application of these methods is simple and can be used routinely in animal or human catheterization, both in the right and left heart.

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THE SIGNIFICANCE OF QS DEFLECTIONS IN THE RIGHT-SIDED PRECORDIAL LEADS: AUTOPSY CORRELATION

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THE right-sided precordial leads display initial negativity in anterior myocardial infarction,[1] anteroseptal myocardial infarction,[2,3] left ventricular hypertrophy,[4,5] right ventricular hypertrophy,[5] and left bundle branch block.[5] This similarity creates difficulty in differential diagnosis which has not been satisfactorily resolved. The present study was undertaken to help clarify this problem.

METHOD

The electrocardiograms of all patients on whom autopsies were performed at the Beth Israel Hospital between Jan. 1, 1947 and Dec. 31, 1951, were reviewed, and those with QS deflections in any one of the Leads V_1, V_2, V_3, or V_{3R} were selected for study.†

These electrocardiograms were classified into 4 groups: Group 1 contained those with rS deflections in V_6 and R deflections in V_6; Group 2 contained those with rS deflections in V_6 and qR, qRs or QS deflections in V_6; Group 3 comprised those with QS deflections in V_6 and qR deflections in V_6; and Group 4 included those displaying QS deflections in V_6 and R deflections in V_6. There were 55 cases in all.

The hearts were studied by the Schlesinger injection and dissection and multiple-section technique.[7] The location of infarcted areas was outlined on a diagram of the unrolled heart as described in a previous publication.[8] Furthermore, the septum was divided into 4 quadrants: anterior apical, anterior basal, posterior apical, and posterior basal. The anterior left ventricular wall was divided into septal, middle, and lateral sections. Each section was further subdivided into basal, middle, and apical areas in the same way that the posterior wall was subdivided[8] (Fig. 1). Infarction in a given region was considered present if it involved over half of the area grossly and was confirmed by microscopic section.

RESULTS

The electrocardiograms fell into the following groups: 18 in Group 1; 11 in Group 2; 9 in Group 3; and 17 in Group 4.

Septal Infarction.—Four cases of Group 1 had acute or old infarctions in all four subdivisions of the septum (Figs. 2 and 3). Two cases had involvement in three areas, and 4 displayed a lesion in two areas. Thus, the septum was

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Received for publication April 1, 1957.

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†Three cases included in the study had qR deflections in these leads consistent with right bundle branch block.

infarcted in 10, and was not involved in 8, of the 18 cases (Figs. 4, 5 and Table I). Both anterior quadrants were involved in 7 cases, and the posterior quadrants in 8 others.

Two of the 11 cases of Group 2 had septal infarction in all four areas (Fig. 6), 3 displayed infarction in two areas, and 2 cases had evidence of it in one area. Thus, 7 cases of this group had infarction of the septum; in an eighth case there was diffuse myocarditis of the septum (Table I). Both anterior quadrants were involved in 5 cases, and both posterior quadrants in 3. There was no evidence of a septal lesion in 3 cases (Fig. 7).

TABLE I. INCIDENCE OF SEPTAL MYOCARDIAL INFARCTION

GROUP	SEPTAL INFARCTION					
	NUMBER OF CASES	PER CENT OF GROUP	ONE	TWO	THREE	FOUR
1.	18	56	0	4 (22)	2 (11)	4 (22)
2.	11	73*	2 (18)	3 (27)	0	3* (27)
3.	9	78	0	1 (11)	0	6 (67)
4.	17	94*	2 (12)	4 (24)	1 (6)	9* (53)

*Diffuse myocarditis in one.
( ) Percentage.

Six of the 9 cases of Group 3 displayed infarction in all four of the subdivisions of the septum (Fig. 8). Of the remaining 3 cases 1 had infarction in two of the areas, and 2 had no septal infarction (Fig. 9). In 1 of the latter no disease of the heart was found at autopsy. Thus, 7 of the Group 3 cases had a septal lesion (Table I). Apical involvement was present in all and basal involvement in 6 of the cases.

Eight of the 17 cases in Group 4 had infarction of all four areas of the septum (Fig. 10), and in a ninth case infarction involved three areas. In 4 cases the involvement included two areas, and in 2 cases one area. No septal infarction was found in 2 cases; in 1 of the latter diffuse myocarditis was present. Thus, the septum was free of disease in only 1 case of Group 4 (Fig. 11 and Table I). In the 16 cases having a septal lesion, the posterior apical quadrant was involved in all instances, the anterior apical area in 14 cases, and the posterior basal and anterior basal quadrant in 11 and 9 cases, respectively.

Anterior Wall Infarction.—Thirteen of the Group 1 cases had anterior wall infarction. The anterior wall overlying the septum was the site of the lesion in 8 cases; in 1 the entire length was involved, in 6 the apical two thirds, and in 1 the apical one third. Thus, in 10 of the 18 cases of Group 1 there was no infarction of the anterior left ventricular wall overlying the septum (Table II).

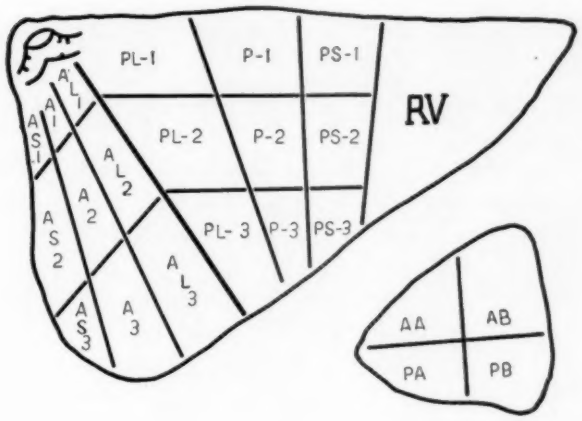

Fig. 1.—The unrolled heart showing the anterior and posterior free walls of the left ventricle subdivided as follows: AS = septal anterior; A = mid anterior; AL = lateral anterior; PL = lateral posterior; P = mid posterior; PS = septal posterior; and 1, 2, 3 = tripartite subdivisions proceeding from base to apex. The septum seen in the lower right-hand corner is subdivided as follows: AA = anterior apical; AB = anterior basal; PA = posterior apical; and PB = posterior basal; RV = right ventricle.

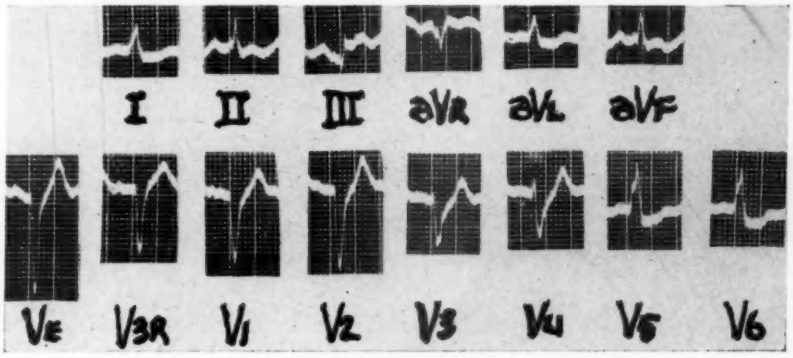

Fig. 2.—Complete left bundle branch block with a QRS interval of 0.13 second. Acute massive infarction of the septum and the anterior and posterior walls was found at autopsy.

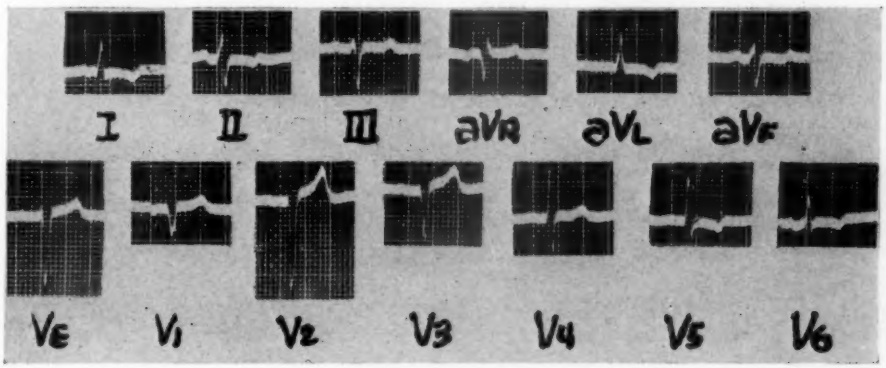

Fig. 3.—Incomplete left bundle branch block with a QRS interval of 0.10 second. At autopsy old infarction of the entire septum and of parts of the anterior and posterior walls was found.

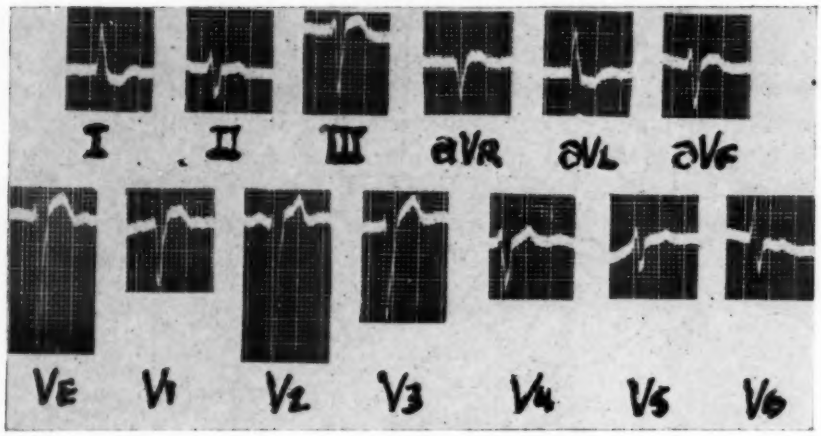

Fig. 4.—Complete left bundle branch block with a QRS interval of 0.12 second. No infarction was found at autopsy.

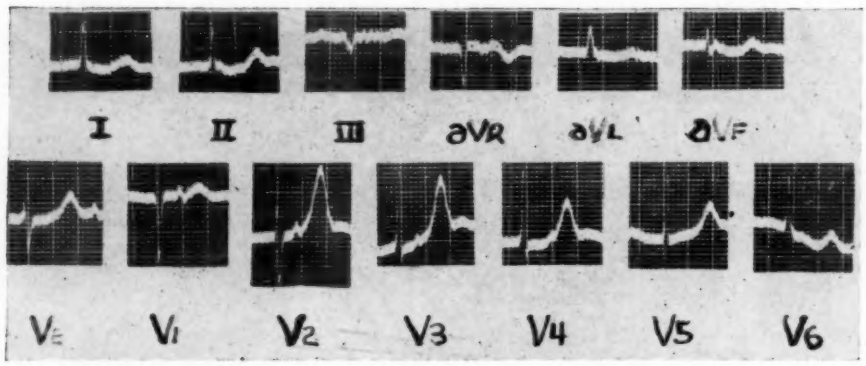

Fig. 5.—Incomplete left bundle branch block and incomplete A-V block; ventricular rate, 30. No myocardial infarction was found at autopsy.

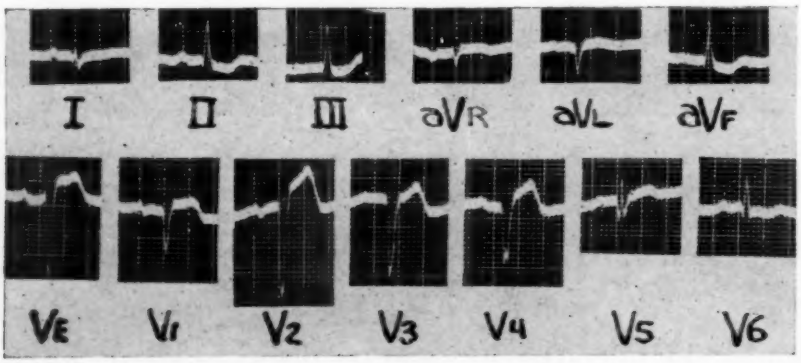

Fig. 6.—Electrocardiogram interpreted as acute anterior myocardial infarction and first degree A-V block. There is initial QRS negativity in all precordial leads except V_6. Autopsy revealed acute myocardial infarction involving all 4 septal quadrants and the anterior and posterior walls.

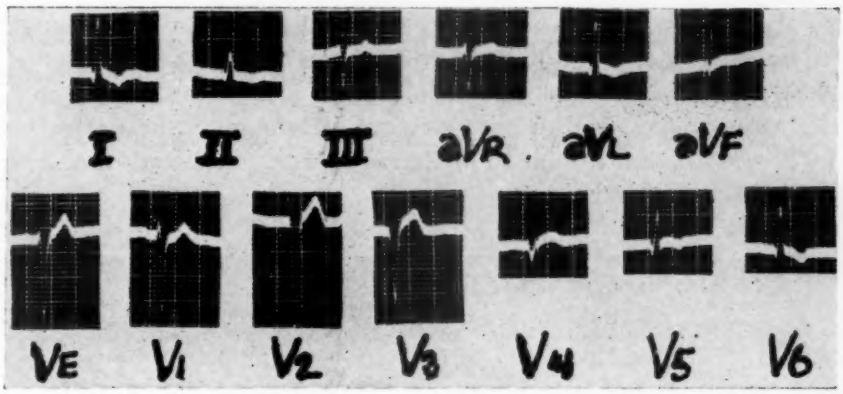

Fig. 7.—There is an initial R in V_e and V_1, and initial negativity in the remaining precordial leads, characteristic of anterior wall infarction. Lead aV_F is consistent with posterior myocardial infarction. Myocardial infarction involving the anterior and posterior walls, but not the septum, was found at autopsy. The anterior wall infarction included the apical two thirds of the septal anterior wall.

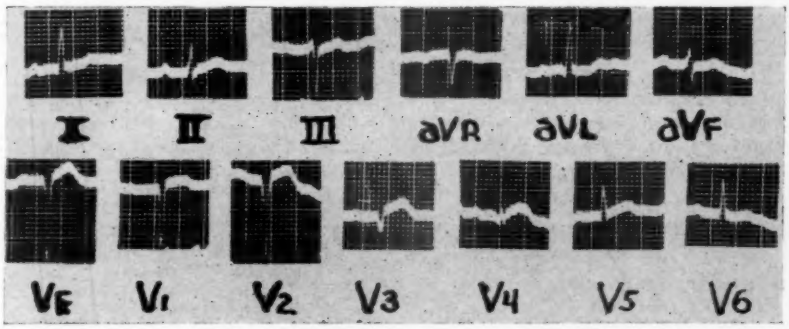

Fig. 8.—QS deflections or q waves in all precordial leads. The QS deflections in V_1, V_2, and V_3 were noted at the onset of the attack; those in V_e appeared 2 days later. Extensive anterior and posterior myocardial infarction also involving all 4 quadrants of the septum was found at post-mortem examination.

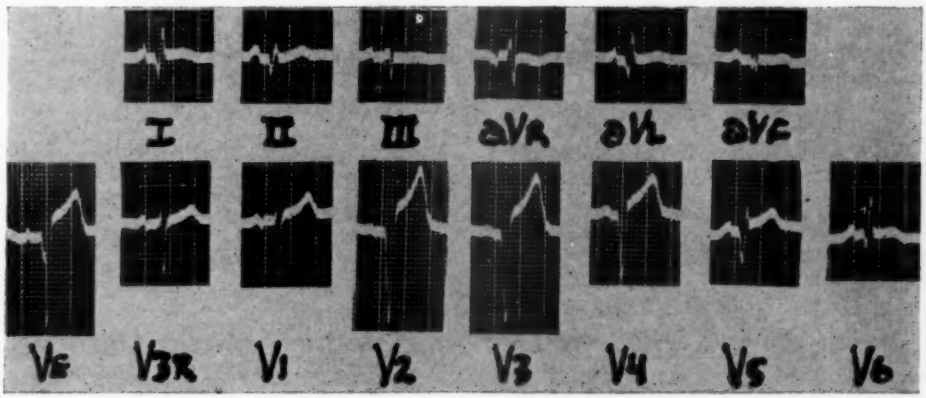

Fig. 9—Initial negativity is present in V_e and V_2-V_6. The diagnosis of anterolateral and posterior myocardial infarction was confirmed at autopsy. The septum was devoid of disease. The QS deflection in V_e was probably due to inferior myocardial infarction.

All 11 cases in Group 2 had anterior wall infarction. The anterior wall overlying the septum was involved in 8 of the 11 cases; the entire length of the septal region of the anterior wall was involved in 3 cases (Table II).

The anterior wall was the site of infarction in 7 of the 9 cases of Group 3; the entire septal region of the anterior wall was involved in 1, the apical two thirds in 2, and the apical one third in 2. The septal anterior wall was uninvolved in 4 cases (Table II).

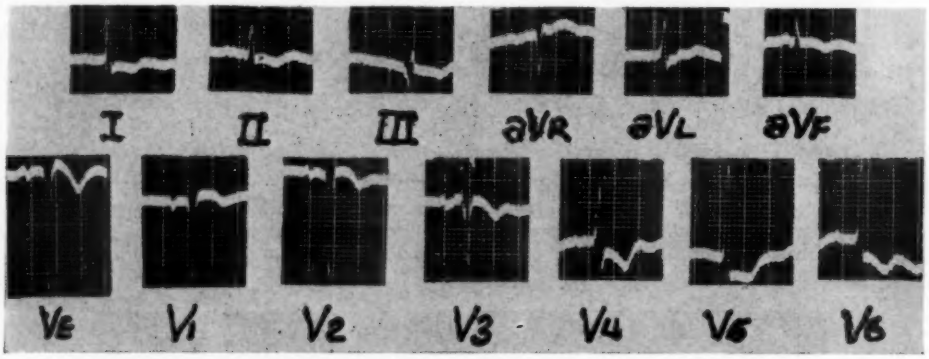

Fig. 10.—The wide slurred Q waves in Leads III and aV_F are consistent with posterior myocardial infarction, and the precordial leads are consistent with acute "anteroseptal" myocardial infarction. Acute infarction of the anterior and posterior walls and of all 4 quadrants of the septum was found at autopsy.

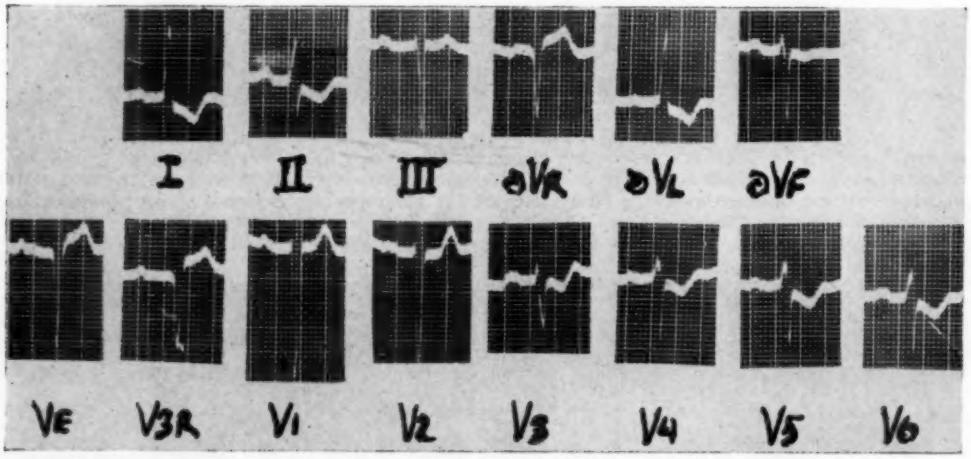

Fig. 11.—The electrocardiogram is similar to incomplete left bundle branch block except for the absence of initial R waves in lead V_6. Infarction involving both the anterior and posterior walls, but not the septum, was found at autopsy.

An anterior wall lesion was noted in all of the 17 cases of Group 4. The lesion involved the anterior wall overlying the septum in 12 cases, the entire length in 4, the apical two thirds in 1, the apical one third in 6, and the middle one third in 1. The anterior wall overlying the septum was uninvolved in 5 cases (Table II).

QRS Interval.—The QRS intervals ranged from 0.06 to 0.20 second (Table III). In Group 1 the QRS intervals were 0.08 to 0.10 second in 10 electrocardiograms, 0.12 second in 2, and 0.13 second or more in 6. Septal infarction was present in 5 of the 10 cases with QRS intervals of 0.10 second or less; in 3 of these, three or more quadrants were involved. A septal lesion was observed in 5 of the 8 cases with QRS intervals of 0.12 second or more; in 3 of these, three or four areas were infarcted.

In Group 2 all but 2 cases had a normal QRS interval (0.10 second or less). One of the remaining 2 cases had right bundle branch block with a QRS interval of 0.12 second. The other, with diffuse myocarditis, had a QRS interval of 0.11 second.

Of the 9 cases of Group 3, all but 2 had QRS intervals of 0.10 second or less. The 2 exceptions had QRS intervals of 0.11 second.

TABLE II. INCIDENCE OF MYOCARDIAL INFARCTION IN THE ANTERIOR WALL OF THE LEFT VENTRICLE OVERLYING THE SEPTUM, AND IN THE POSTERIOR WALL

GROUP	CASES	ANTERIOR MYOCARDIAL INFARCTION	SEPTAL ANTERIOR MYOCARDIAL INFARCTION*				POSTERIOR MYOCARDIAL INFARCTION
			1 AREA	2 AREAS	3 AREAS	TOTAL	
1.	18	13 (72)	1	6	1	8 (44)	13 (72)
2.	11	11 (100)	2	2	4	8 (73)	11 (100)
3.	9	7 (78)	2	2	1	5 (56)	8 (89)
4.	17	17 (100)	7	1	3	11 (65)	17 (100)

( ) Percentage.
*Infarction of free wall of the left ventricle overlying the septum.

TABLE III. INCIDENCE OF QRS INTERVALS

GROUP	NUMBER OF CASES	QRS INTERVAL IN SECONDS		
		0.10 OR LESS	0.11 TO 0.12	0.13 OR MORE
1.	18	10	2*	6
2.	11	9	2	0
3.	9	7	2	0
4.	17	12	3*	2*

*Right bundle branch block in one.

The QRS interval was 0.08 to 0.10 second in 12, and 0.11 second in 2 of the 17 cases of Group 4. Two of the 3 remaining cases had right bundle branch block with QRS intervals of 0.12 and 0.15 second, respectively. In the last case the QRS interval was 0.13 second; the pattern of bundle branch block was not present.

Thus, with the exception of the cases of right bundle branch block, the QRS interval was greater than 0.11 second in only 1 case of the combined Groups 2, 3, and 4.

DISCUSSION

QS deflections in the right-sided precordial leads are not necessarily diagnostic of infarction of the interventricular septum. This is indicated by the absence of septal lesions in 29 per cent of the cases, despite the high incidence of myocardial infarction (87 per cent) in the whole series. As can be seen in Table II, there was an almost equal frequency of myocardial disease in the anterior and posterior walls of the left ventricle. This is explained by the method of selection of cases, and is probably an indication that QS deflections in the right precordial leads are an important sign of myocardial infarction.

The Group 1 pattern is not diagnostic of either septal or "anteroseptal" infarction, as can be seen from the relatively low incidence of infarct in the septum and septal anterior wall, 56 and 45 per cent, respectively. Moreover, it is noteworthy that no myocardial lesion was found in 5 of the 18 cases.

It is probable that most, if not all, of the Group 1 electrocardiograms represent complete or incomplete left bundle branch block. The initial forces in the limb and precordial leads are consistent with this conduction defect.[5] Thus, initial negativity is found invariably in aV_R, commonly in aV_L, and rarely in Lead I; initial positivity occurs in aV_F without exception. QS deflections commonly occur in Leads V_1 and V_2 in left bundle branch block, and it is not possible on the basis of these QRS abnormalities alone to distinguish those cases which do from those which do not have infarction in addition to left bundle branch block. So far as the electrocardiographic correlation with histologic lesions is concerned, no relationship between the degree of block and either the presence or extent of septal myocardial infarction was demonstrable in Group 1.

In Group 2, Q waves or QS deflections were observed in all, or most, of the precordial leads, with the exception of V_6. Infarction of the anterior wall was found in all cases of this group at autopsy. Involvement of the septum, however, was not demonstrable histologically in over one third of this group; extensive septal infarction, i.e., involvement of three or four quadrants, was observed in only one fourth of the cases of Group 2.

There is a striking disparity in the incidence of septal infarction in Groups 2 and 3. This is especially noteworthy because the two groups are electrocardiographically similar except for the presence in Group 3 of initial negativity in V_6. Anterior wall infarction was present in 7 of the 9 cases of Group 3, and posterior infarction in 8. Infarction was not present in the ninth case and the heart was normal in all respects. No explanation for the "abnormal" electrocardiogram was found at post-mortem examination. This is the only instance

of a QS deflection in V_e in a normal heart, in our experience. Excluding this exceptional case, however, the septum was free of infarction in only 1 case. Extensive septal infarction was present in two thirds of the group.

Group 4, like Group 2, was outstanding in that an anterior wall lesion was present in every case. However, there is a striking contrast in relation to septal disease. In only 1 of the 17 cases of Group 4 was the septum normal, compared to over one third of the cases of Group 2. This emphasizes again the importance of a QS deflection in V_e in the diagnosis of septal infarction. In the entire series there was a QS deflection in V_e in 26 cases, and an initial r wave in 29; in the former, septal infarct was found in 23, and in the latter, in 18 cases.

The initial forces hold the clue to the diagnosis of septal infarction, since the septum contains the first fraction of ventricular muscle to be depolarized. In most normal electrocardiograms these forces are directed anteriorly and to the right, and superiorly or inferiorly, depending on the position of the heart and its rotation. Any displacement of these forces indicates an abnormal order of depolarization of the septum or destruction of significant portions of it, i.e., left bundle branch block or myocardial infarction (or other lesions), respectively.[9]

In the normal electrocardiogram the initial deflections in the right-sided leads and Lead V_e are positive with rare exceptions, and there is initial negativity in the left-sided precordial leads, notably V_6. In left bundle branch block the initial depolarization forces are directed anteriorly, to the left and inferiorly. Therefore, initial negativity may occur in the right-sided precordial leads but is absent in the left precordial leads. The anterior and inferior direction of these forces is responsible for the initial r deflection in V_e (Group 1).

Significant disease of the interventricular septum also produces a change in the direction of the initial depolarization forces.[10] Leads V_1 to V_6 may resemble left bundle branch block as a result of the leftward orientation of the initial depolarization forces, but their posterior displacement produces initial negativity in the anterior and inferior Lead V_e.

The significance of V_e in the diagnosis of extensive septal infarction is further borne out by comparing Group 2 with Groups 3 and 4. In only a little over one fourth of the cases of Group 2 were three or more septal quadrants infarcted; in Groups 3 and 4, on the other hand, close to two thirds of the cases displayed massive involvement of the septum.

In the electrocardiograms of Group 3, as in those of Group 4, the initial negativity in the precordial leads suggests that the initial forces are posteriorly directed, i.e., they may be oriented to the right and posteriorly or directly posteriorly. In the latter event they would be perpendicular to one or more of the left-sided precordial lead axes; the initial forces in these leads, therefore, would be represented by an initial isoelectric interval instead of a q wave. This would explain the equally high incidence of septal infarction in Groups 3 and 4, i.e., in those with and without q waves in the left precordial leads. The electrocardiographic patterns in Groups 3 and 4 indicate septal infarction to a high degree.

In 2 cases of Groups 3 and 4 combined (26 cases) one quadrant of the septum, and in 5 cases two quadrants, displayed a lesion; the infarct involved some portion

of the apical septum in all 7. Two of the cases in Groups 1 and 2 combined (29 cases) displayed a lesion in one quadrant, and 7 cases in two quadrants; the apical part of the septum was involved in 7 of the 9 cases. Thus, there appears to be no relation between involvement of specific portions of the septum and the electrocardiographic pattern of septal infarction.

A diagnosis of septal involvement in cases of acute myocardial infarction can be made when serial tracings reveal changes of concomitant acute anterior and posterior myocardial infarction, or the appearance of high grade A-V block or bundle branch block.[4,5,6,11] However, electrocardiographic criteria in stable tracings for the detection of infarction of the septum have not been described. The above observations indicate that QS deflections in one or more of the right-sided precordial leads is strongly suggestive of septal anterior wall infarction rather than infarction of the septum itself, providing left bundle branch block can be excluded. A QS deflection in V_6 tends to rule out left bundle branch block, and is, therefore, diagnostic, to a high degree, of infarction of the interventricular septum.

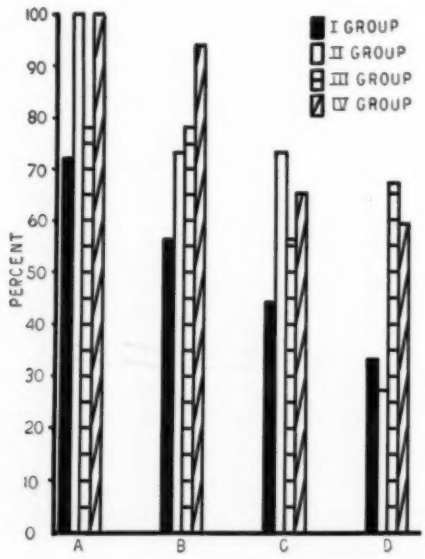

Fig. 12.—Incidence of anterior, septal, anteroseptal, and massive septal infarction. *A*, Anterior myocardial infarction. *B*, Septal myocardial infarction. *C*, Anteroseptal myocardial infarction. *D*, Massive septal myocardial infarction.

There is a moderate association of septal and septal anterior wall infarction; in the 32 cases with septal anterior wall infarction there was some involvement of the septum in 21, massive in 16. Fig. 12 shows that the incidence of disease of the anterior wall overlying the septum in each group roughly parallels the incidence of anterior wall infarction (columns *A* and *C*) but bears no relationship to the incidence of septal infarction (columns *B* and *D*). While the occurrence of "anteroseptal" infarction and anterior wall infarction is equally great in Groups 2 and 4, the incidence of septal disease is quite different, particularly in relation

to massive involvement. Excluding cases of left bundle branch block, QS deflections in the right-sided leads are diagnostic of anterior infarction, frequently including the region overlying the septum. When QS deflections are also present in V_6, significant septal involvement is highly probable.

SUMMARY

1. The hearts of 55 patients in whom the electrocardiograms displayed QS deflections in the right-sided precordial leads were studied at autopsy for disease of the septum and overlying anterior wall myocardium.

2. The electrocardiograms were divided into 4 groups on the basis of the initial QRS deflections in V_6 and V_6.

3. QS deflections in the right precordial leads were associated with anterior myocardial infarction and septal myocardial infarction. With one exception, a myocardial lesion was present when there was a QS deflection in V_6.

4. The highest incidence of septal infarction was associated with initial negativity in V_6, i.e., QS or qR deflections.

5. Left bundle branch block occurred only in Group 1, i.e., in electrocardiograms in which initial positivity of the QRS complex was displayed in V_6, V_6, and aV_F. In this group q waves were common in aV_L and rarely present in Lead I, and initial negativity was invariably registered in aV_R. When myocardial infarction was present, it was concealed by the pattern of left bundle branch block.

6. There was a positive correlation between the type of electrocardiogram and septal myocardial infarction, but no specific fraction of septum appeared to be crucial in the genesis of the electrocardiographic pattern of septal infarction.

7. There is no relationship between involvement of the anterior wall overlying the septum and the electrocardiographic pattern, but involvement of this portion of the myocardium is most common in anterior wall infarction.

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CONGENITAL AORTIC SEPTAL DEFECT

Clinical and Surgical Considerations of Three Cases

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CONGENITAL aortic septal defects are considered infrequent developmental anomalies, only 34 cases having been reported up to January, 1956.[1] In the vast majority of these the correct diagnosis was made by the surgeon or pathologist. Only 7 cases were diagnosed during life. In 2 of these the defect was recognized by heart catheterization, in 3 by means of retrograde aortography; in only 2 cases was the diagnosis made clinically.[2]

We observed 3 cases of congenital aortic septal defect which had been sent to surgery diagnosed as patent ductus arteriosus. The true nature of the anomaly was discovered at the operating table. Two of the patients were adults. It is the purpose of this report to discuss the clinical and surgical findings of these cases.

CASE REPORTS

Case 1.—A girl aged 11 years was found to have a heart murmur. She was symptom-free, but was underdeveloped. The apex beat was seen and felt in the fifth left intercostal space (LIS) at the mid-clavicular line. A systolic thrill and a continuous murmur were present at the second LIS, +++ intensity,* propagated to the whole precordium and neck. Brachial artery pressure was 125/65 mm. Hg. An ECG was considered normal (Fig. 1). X-ray studies showed a normal cardiac shadow; a phonocardiogram confirmed the auscultatory findings (Figs. 2,3,4). Cardiac catheterization data are given in Table I.

Table I

	Pressure (mm. Hg)			Oxygen content (vol. per cent)
	Maximum	Minimum	Mean	
Pulmonary artery	30	10		14.42
Right ventricle	38	1		12.99
Right auricle			2	12.75

Femoral arterial blood saturation: 15.62 vol. per cent: 90.28 per cent
Oxygen capacity: 17.30 vol. per cent

Received for publication April 2, 1957.

*The intensity of thrills and murmurs are classed from + to +++.

With these findings, a diagnosis of patent ductus arteriosus was made, and the patient was sent to the surgeon, who found a closed ductus arteriosus, and a thrill at the base of the heart, 2 cm. from the root of the aorta. Closure of the defect was not attempted.

CASE 2.—A 44-year-old woman complained of dyspnea on effort and palpitation of 9 years' duration. She had noted bilateral ankle edema during the last year. Physical examination revealed arterial dance in the neck and water-hammer pulse. The apex beat was seen and felt in the fifth LIS beyond the mid-clavicular line. A systolic thrill and a continuous murmur with systolic accentuation were present at the first and second LIS, +++ intensity. At the mitral area a protodiastolic murmur of low tone, and clearly discernible from the continuous murmur, was auscultated. Brachial artery pressure was 150/70 mm. Hg. The ECG showed left ventricular hypertrophy and strain, and digitalis effect (Fig. 5,*A*). X-ray examination showed slight cardiac enlargement, the pulmonary artery and aortic knob being exceedingly prominent, with augmented pulmonary markings (Fig. 6). A calcification of the pulmonary artery, seen in the plain x-ray film, was confirmed in planigraphy.

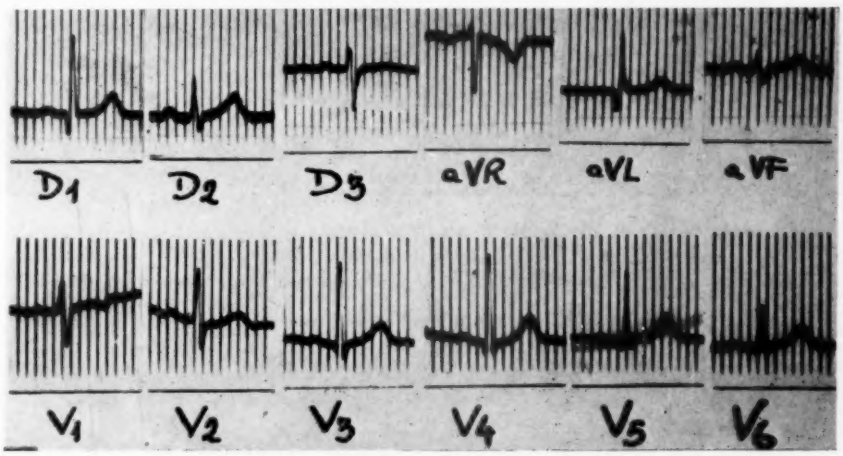

Fig. 1.—Case 1. The ECG shows left axis deviation only.

The patient was sent to the surgeon (Dr. Perianes) with a diagnosis of patent ductus arteriosus. The surgeon's report was as follows: "The aorta is slightly diminished in size, the trunk and left branch of the pulmonary artery being exceedingly large, almost aneurysmatic; the right branch of the pulmonary artery is not visualized. A thrill is palpated in the ascending aorta, and with greater intensity at the pulmonary trunk. After the pericardium was opened, an aortic pulmonary fistula was found, at a distance of 2 cm. from the root of the great vessels, anteriorly located. The visceral pericardium, which extends to the pulmonary trunk, is dissected, the fistula isolated, and 4 ligatures of silk are adjusted on an artificially created cone of the wall of the pulmonary artery."

In the postoperative period the continuous murmur disappeared, with a soft systolic murmur remaining, + intensity; the brachial artery pressure was 150/110 mm. Hg (having been 148/70 before the operation). A paralysis of the left laryngeal nerve was observed. In the postoperative ECG, taken 60 days after closure of the defect, the left heart strain had disappeared, as had almost the left ventricular hypertrophy (Fig. 5,*B*). X-ray examination showed a diminished convexity of the pulmonary artery and its branches (Fig. 7). The symptoms disappeared completely, and digitalis was discontinued in the immediate postoperative period.

CASE 3.—A 22-year-old woman was found to have a heart murmur at the age of 16 years. When she was 18 years old (in 1952), she was operated upon elsewhere, with the diagnosis of patent ductus arteriosus, but the continuous murmur persisted after the operation. She was first examined by us in March, 1954, at the age of 20 years. She complained of progressive dyspnea

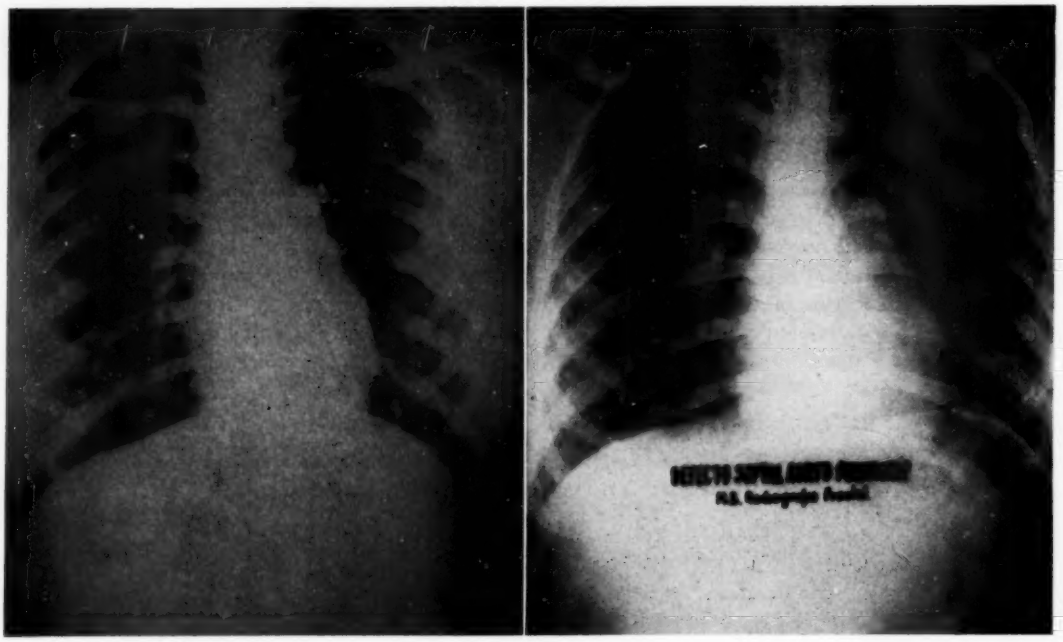

Fig. 2. *Fig. 3.*

Fig. 2.—Case 1. X-ray shows a little prominence of the pulmonary arch.

Fig. 3.—X-ray of Case 1 made in 1952, two years after that of Fig. 2.

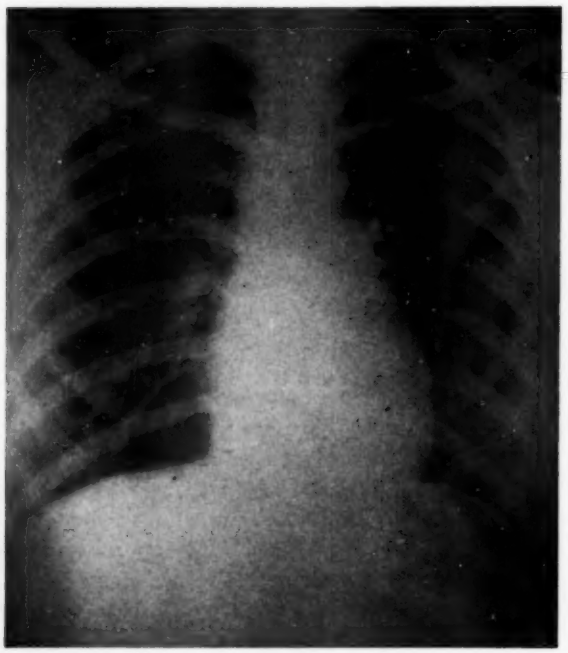

Fig. 4.—X-ray of Case 1 made in 1956, four years after that of Fig. 3.

on effort, and palpitation. Physical examination showed a well-developed young woman. Arterial dance was present in the neck. The apex beat was seen and felt at the sixth LIS, 2 cm. beyond the mid-clavicular line. A continuous thrill was present at the pulmonary area. On auscultation a continuous murmur with systolic accentuation was heard at the second LIS, the systolic component being propagated to the whole precordium and scapular region. The second heart sound was loud at the pulmonary area. Brachial artery pressure was 145/65 mm. Hg. The ECG showed signs suggestive of left ventricular hypertrophy (Fig. 8). On x-ray examination the heart was slightly enlarged, and dilatation of the ascending aorta, pulsatile hila, and augmented pulmonary markings were present (Fig. 9). Cardiac catheterization data are given in Table II.

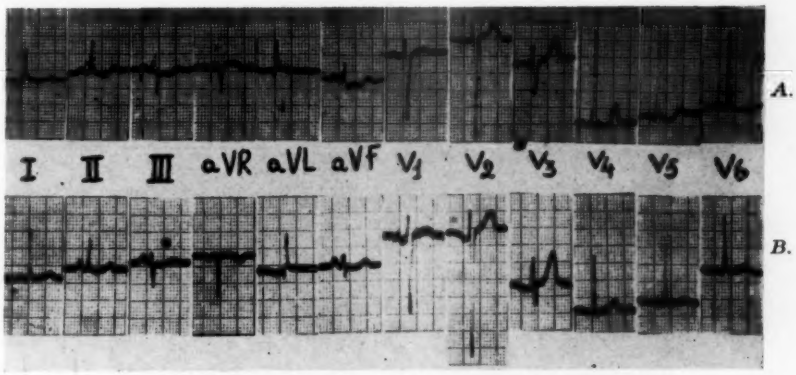

Fig. 5.—Case 2. *A*, ECG before operation shows left ventricular hypertrophy and strain, and digitalis effect. *B*, Two months after operation the left ventricular hypertrophy and strain have disappeared.

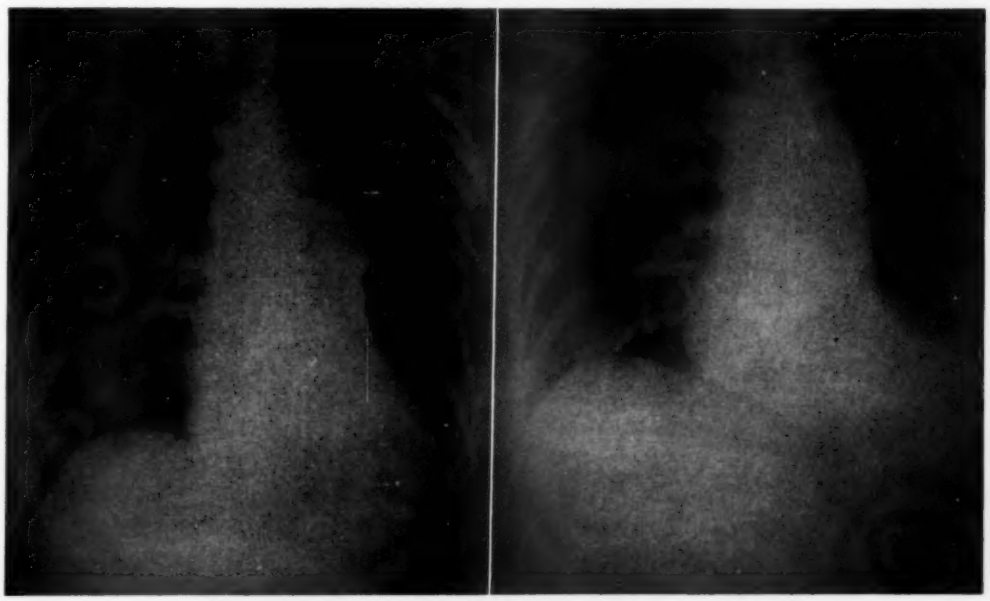

Fig. 6. *Fig. 7.*

Fig. 6.—Case 2. X-ray shows slight cardiac enlargement; pulmonary artery and aortic knob are prominent.

Fig. 7.—Case 2. Two months after operation, the x-ray shows diminished convexity of the pulmonary artery and its branches; little pleural effusion persists.

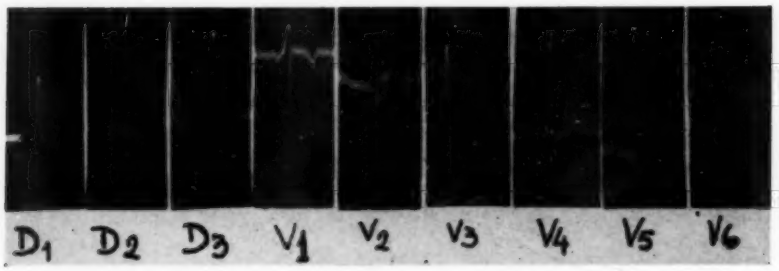

Fig. 8.—Case 3. ECG before operation shows left ventricular hypertrophy.

Fig. 9.—Case 3. X-ray before operation shows moderate enlargement of the heart, augmented pulmonary markings, and dilatation of the ascending aorta.

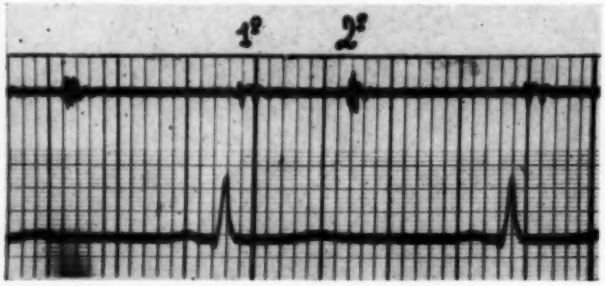

Fig. 10.—Case 3. Phonocardiogram after operation shows disappearance of the continuous murmurs.

TABLE II

	PRESSURE (MM. Hg)			OXYGEN CONTENT (VOL. PER CENT)
	MAXIMUM	MINIMUM	MEAN	
Pulmonary artery	23	13	17	13.42
Right ventricle	31	1	15	11.45
Right auricle	3	0.5	1.5	11.08
Femoral artery				14.53

A diagnosis of patent ductus arteriosus was made, and the patient was operated upon in July, 1956. The surgeon found a closed ductus arteriosus, the pulmonary trunk being considerably dilated. At the root of the great vessels a continuous thrill was palpated. A diagnosis of congenital aortic septal defect was made, located 2 cm. from the root of the aorta, and measuring 7 mm. in diameter. The communication was isolated, and 5 ligatures were placed in it. The continuous murmur disappeared, with a soft systolic thrill remaining in the pulmonary valve area, probably originating in a relative pulmonary stenosis, which in turn was due to the dilatation of the pulmonary trunk (Fig. 10).

Fig. 11.—Case 3. X-ray after operation shows diminished cardiac enlargement.

The patient left the hospital after a week, symptoms and signs having disappeared; the brachial artery pressure was 120/80 mm. Hg. X-ray study showed diminished heart size and pulmonary markings, and a left pleural effusion, with a high left hemidiaphragm (Fig. 11). On the ECG signs of left ventricular hypertrophy had disappeared.

DISCUSSION

In the 3 cases presented herein, the clinical diagnosis was erroneous, the nature of the anomaly not being discovered until surgery. This diagnostic error is (as in the majority of the reported cases) somewhat justifiable in the absence of distinctive physical signs which differentiate this entity from patent ductus arteriosus, the vascular malformation with which it is most commonly confused.

It has been mentioned[3] that in congenital aortic septal defect the localization of the murmur and thrill is somewhat lower than in patent ductus arteriosus, being in the third or fourth LIS rather than in the first or second. This point of difference, however, was not observed in our patients. It may be of interest to note that in 1 of our patients a mitral protodiastolic murmur also was heard. This finding is considered as evidence of considerable arteriovenous shunt, when observed in cases of patent ductus arteriosus.[16]

Concerning the x-ray findings, it has been suggested that when the augmented aortic pulsation is observed in the ascending aorta, rather than in the aortic knob, a congenital aortic septal defect should be suspected. Again, this sign was not present in our patients, although it should be noted that Case 3 showed dilatation of the ascending aorta on the plain x-ray film.

Two procedures of definite diagnostic value are available in the recognition of this condition: (1) retrograde aortography,[4] showing a simultaneous filling of the aortic and pulmonary trunks, and (2) catheterization of the defect itself, the catheter's position in the ascending and descending aorta allowing the recognition of the defect's position.[1] It should be noted that the hemodynamic data are the same in both conditions, in the absence of right-to-left shunt. In the latter situation a diminished saturation of the femoral, and sometimes of the left brachial, arterial blood is found, compared with the right brachial, in cases of patent ductus arteriosus with reversed flow, and not in congenital aortic septal defect in which the arterial unsaturation is found in the four limbs. Incidentally, it is of interest to mention that our 2 cases in which hemodynamic studies were performed had normal pulmonary arterial pressure. Other authors[3] have found high pulmonary artery pressure and resistance in these cases.

Congenital aortic septal defect may closely simulate patent ductus arteriosus, even if hemodynamic studies are made, unless the catheter can be passed through the defect. Therefore, the cardiovascular surgeon should be prepared to manage adequately this condition when he finds it, since its closure is somewhat more complicated, more time consuming, and more hazardous than is the common cause of patent ductus arteriosus.

SUMMARY

The authors have reported 3 cases of congenital aortic septal defect, in 2 of which cardiac catheterization studies were made.

No significant clinical, electrocardiographic, radiologic, or hemodynamic differences were found between this anomaly and patent ductus arteriosus. Accordingly, the diagnosis was wrong in all cases.

The first case was surgically explored, but closure was not attempted; in the last 2 cases the defect was successfully closed, with disappearance of symptoms and signs.

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BALLISTOCARDIOGRAPHIC CHANGES DURING A 30 DAY PHYSICAL TRAINING PERIOD

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FOUR direct body acceleration ballistocardiograms* were obtained from a man, aged 40 years, who for a period of 30 days underwent a physical conditioning course. When first seen he was free of serious illness, although his physical performance was poor. An activity program was elaborated for him, consisting of daily training periods, of 90 minutes each, of calisthenic exercises, apparatus gymnastics, weight lifting, and swimming. In the beginning, the calisthenic exercises had to be interrupted every 2 minutes to give the subject time to "recapture his breath." On the high horizontal bar he could perform one pull-up. He lifted only 20 pounds, repeating the effort up to 10 times. He swam not more than 3 lengths in the standard-size swimming pool.

After the 30 days' training period, he went through an uninterrupted sequence of calisthenic exercises of 10 minutes' duration, did 8 pull-ups on the horizontal bar, and performed a number of movements on the parallel bars and the side horse which he had been unable to do 4 weeks earlier, lifted 80 pounds 20 times in succession, and swam 12 full lengths in the pool.

The first ballistocardiogram was taken before the experiment; the second after the first 10 day training period; the third after 20 days; and the fourth at the end of 30 days. All tracings are of Grade 1. Therefore, we are dealing with a functionally normal heart.

A number of features of the Grade 1 tracings varied with the subject's changing state of physical fitness. Thus, we can assess cardiovascular efficiency within the range of the physiologic norm. The initial tracing (Fig. 1,*a*) reflects functional normality, because every systolic contraction can be identified; because the 3 main waves, I, J, and K, are present throughout; and because the ballistic complexes are repetitive. In terms of efficiency, however, the tracing is only of "medium" quality, because there is tachycardia at rest; because the difference in amplitudes of the largest and the smallest IJK complexes is greater than 50 per cent; and because the form pattern of the complexes changes significantly with respiration and presumably also with diastolic influx of blood into the heart. We mention without comment at this stage that notching is present on several JK strokes.

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Received for publication April 8, 1957.

*The calibrated acceleration ballistocardiograph of the Industrial Development Laboratories, Jersey City, N. J., was used in this study.

In the second tracing (Fig. 1,*b*) systolic deflections are more distinct as compared with Fig. 1,*a*; the difference between amplitudes of the largest and smallest IJK complexes are less marked; and the force pattern remains more identical throughout. No notching can be seen on JK.

In the third tracing (Fig. 1,*c*) pulse rate at rest is again slower. Cardiac contractions are very regular, of considerable strength, and amplitudes of systolic complexes do not alter appreciably.

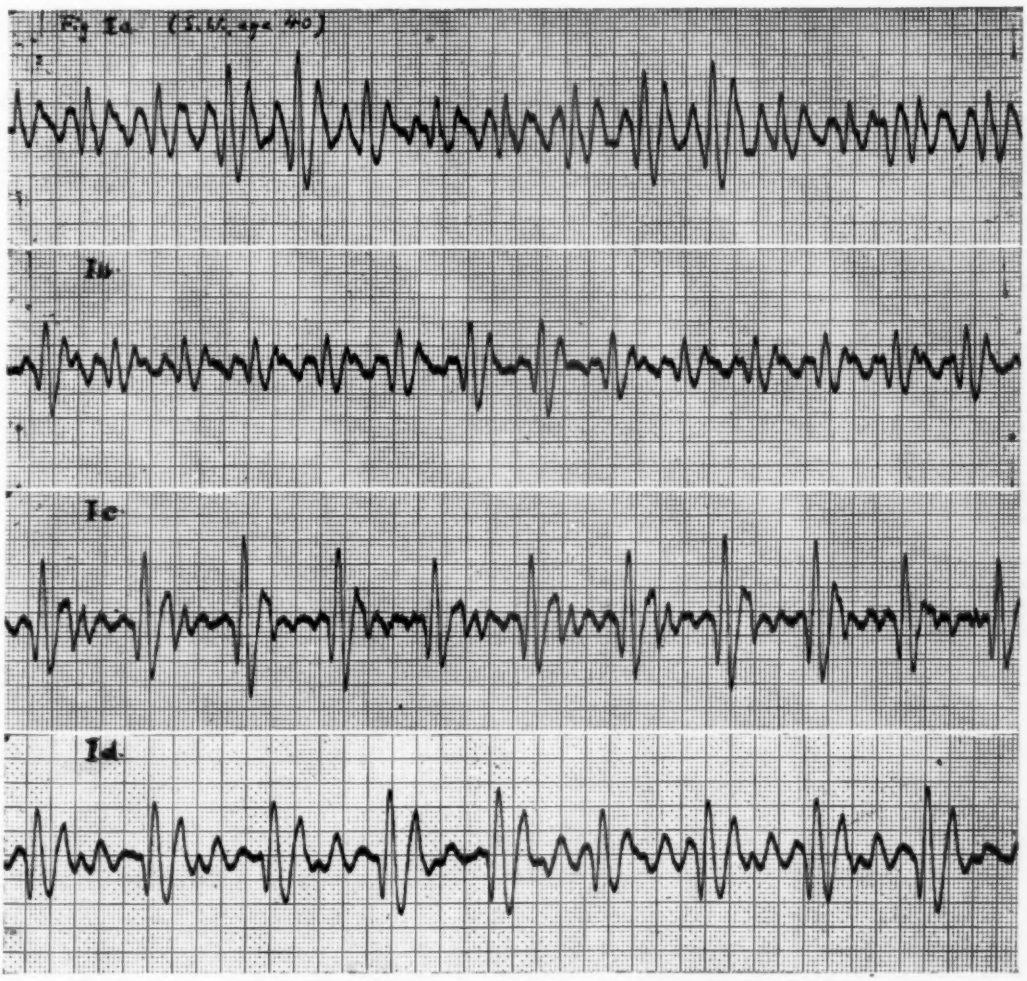

Fig. 1.

The fourth tracing (Fig. 1,*d*) reveals a further slowing down of pulse rate at rest, which now is around 65, as compared to 105, 4 weeks earlier. Mean amplitudes of IJ and JK are lower at rest. The significance of this observation will be detailed presently. Finally, the percentage scope of the differences of extreme amplitude deviations of the systolic deflections is small compared with corresponding findings in the beginning of the training period.

TABLE I. ANALYSIS OF THE 5 BALLISTOCARDIOGRAPHIC TRACINGS

QUANTITATIVE SUBANALYSIS		S.W.*—30 DAYS' PHYSICAL TRAINING PERIOD								P.M.** (DECATHLON CHAMPION, 1956) AT REST	
		BEFORE		DURING				AFTER			
		FIG. 1,*a*		FIG. 1,*b*		FIG. 1,*c*		FIG. 1,*d*		FIG. 2	
		L	S	L	S	L	S	L	S	L	S
Amplitude (depth)		8	5	5	3	9	8	10	8	8	5
Time—down—stroke of I		.04	.03	.04	.03	.04	.03	.03	.03	.03	.03
Time total I		.07	.05	.06	.05	.06	.06	.05	.06	.05	.06
Amplitude up-stroke (height of J)		17	6	10	6	18	13	14	9	9	9
Time (width) IJ segment		.06	.04	.05	.05	.04	.05	.05	.05	.08	.07
Time (width) total J		.06	.07	.06	.07	.06	.06	.08	.07	.09	.07
Amplitude JK down-stroke		12	4	11	4	16	9	12	8	13	12
Time (width) JK segment		.08	.11	.07	.09	.08	.07	.10	.11	.08	.09
Ratio of I wave to IJ wave (I/IJ)		.32	.45	.33	.33	.33	.38	.42	.47	.45	.45
Amplitude of IJ segment		25	11	15	9	27	21	24	17	17	11
Amplitude of JK segment		29	10	21	10	34	22	26	17	22	18
Time (width) IK		.14	.15	.12	.14	.14	.12	.15	.16	.16	.16
Heart Rate Equivalent	Slowest sequence of 3 complexes	100		100		74		63		38	
	Fastest sequence of 3 complexes	110		102		79		68		40	

All ballistocardiograms are Grade 1.
***Aged 40 years.**
****Aged 24 years.**

A fifth ballistocardiogram is presented (Fig. 2). It was obtained at rest from Mr. P. M., aged 24 years, one of the ten best decathlon men of the United States in 1956. It reveals a resting bradycardia of under 40 beats per minute; striking regularity of IJK amplitudes; and a restricted systolic force display. The latter is characteristic of superbly trained athletes who, as Reindell was the first to recognize, use only a fraction of the kinetic contraction potential of the myocardium when at rest. This is a special feature which has been discussed elsewhere,[1,2] and which should not detract from the significance of the early increase

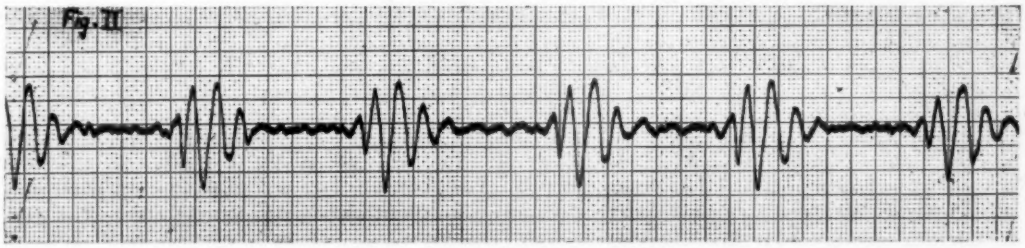

Fig. 2.

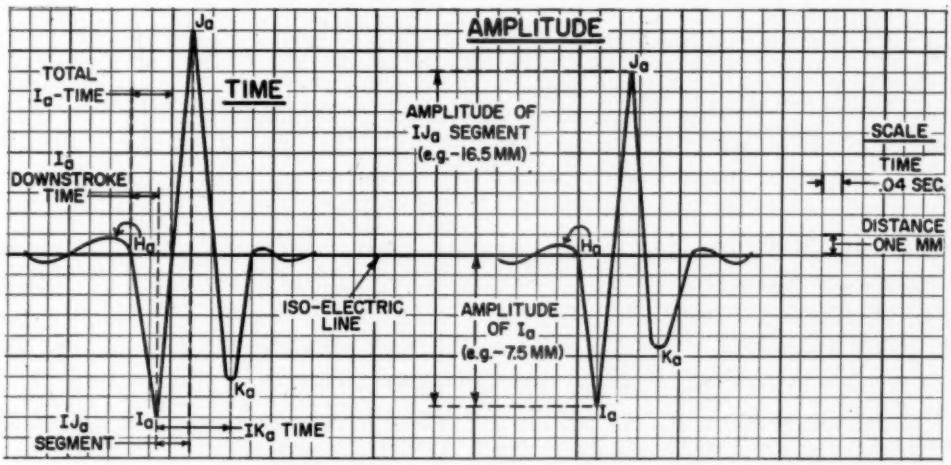

Fig. 3.

with training of systolic force, as shown in Fig. 1,*a-c*, reflecting a distinct functional improvement. However, it is noteworthy that at the end of the fourth week of training of the 40-year-old subject under study, there had occurred an adaptive shift towards the pattern which distinguishes the BCG of Mr. P. M., decathlon athlete.

Fig. 3 explains the two main principles for the quantitative evaluation of the normal ballistocardiogram in terms of amplitudes and time variants of the systolic complex. In Table I the 5 ballistocardiographic tracings are analyzed. Not all of the figures are discussed in the text but we shall refer again to the evidence in subsequent communications. The physiologic and clinical interpretation of ballistocardiography is now in its infancy. It is therefore imperative that concise case material of the kind under reference be placed on record.

SUMMARY

Summarizing, the evidence indicates that ballistocardiography is capable of yielding cardiac records which reflect different degrees of physical fitness of healthy subjects; that the method under reference is amenable to quantitative evaluation; and that a daily exercise program of the kind under review can lead to a significant improvement in cardiac efficiency, concomitant with a gain in athletic performance standards, in a month's time in a previously untrained man of 40 years of age. This communication is confined to the discussion of tracings obtained at rest. The reaction of the ballistocardiogram to exercise will be considered in separate reports.

ADDENDUM

In view of the fact that ballistocardiography appears to reflect levels of physical efficiency even within the scope of physiologic norms, it is relevant to place on record precise information of Mr. P. M.'s athletic performances at the 1956 decathlon championships. Running times are given in seconds and minutes; jumping and throwing results according to English as well as metric scales; and point values for each performance are expressed after the decathlon table of the International Athletic Association:

100 meters: 11.3 (800)
broad jump: 20-9½; 6.34 (597)
shot put: 42-4¼; 12.9 (663)
high jump: 5-10; 1.78 (746)
400 meters: 51.4 (744)
110 meter hurdles: 15.3 (740)
discus: 124-5¾; 37.94 (571)
pole vault: 12-0; 3.66 (580)
javelin: 165-9½; 50.54 (538)
1500 meters: 5:04.2 (234)

Total point aggregate, 6,213. Mr. P. M. is 24 years of age, 6′ 3¼″ (1.91 M.) tall, weighs 192 pounds (87 Kg.), with body index of 238.

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RESPONSE OF COUPLING OF EXTRASYSTOLES TO WARMING AND COOLING THE FOCUS OF ORIGIN

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THE mechanism of origin of extrasystoles has not yet been definitely established. While some authors attribute them to a circumscribed circus movement at their focus of origin, others feel that most extrasystoles are due to the firing of impulses in an ectopic center. Actually, it may be assumed that there is more than one mechanism, and a circus movement has actually been proved under special conditions, leading to what are known as return extrasystoles.[8] However, it is probable that the basis for the vast majority of coupled extrasystoles is the same and is due to stimuli fired from an ectopic focus.

The experimental study of coupled beats is difficult because they can be elicited by only a few procedures.[7] It is known that they appear after the topical application of certain substances, such as barium chloride, sodium chloride, acetylcholine, digitalis, or strophanthin, on the cardiac surface. However, these extrasystoles are transient and last for only a few minutes. Therefore, it is difficult to study their variations under planned conditions. Veratrine, which causes a marked increase of the negative after-potential and therefore prolongs the supernormal phase, leads by itself to a parasystolic arrhythmia rather than to coupled extrasystoles. Lately, however, it has been shown that coupling does occur when veratrine is used locally in conjunction with inhalation of a mixture of 20 per cent carbon dioxide and 80 per cent oxygen. The duration of the arrhythmia thus elicited is sufficiently long to enable experimental studies to be carried out.[6]

The object of this study was to determine the influence of temperature changes at the focal area on the length of coupling.

METHOD

The experiments were performed on 23 dogs. The animals, anesthetized with morphine and Nembutal, were intubated, the sternum and adjacent part of the ribs resected, and the heart exposed by opening the pericardium. The vagus nerves were divided in the neck. Veratrine was then injected subepicardially on the conus of the right ventricle, as described in a previous paper,[6] and the respirator was attached to a tank containing the CO_2-O_2 mixture. The warming and cooling was done with test tubes filled with water heated to 60° Celsius, and with ice cooled water. The electrocardiogram was registered exclusively in Lead II.

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This investigation was supported in part by a research grant from the National Heart Institute, United States Public Health Service.

Received for publication April 9, 1957.

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RESULTS

The results were uniform and are illustrated in Figs. 1 and 2. The combination of veratrine and carbon dioxide evoked extrasystoles (Fig. 1) which appeared after every fifth to seventh sinus beat; they had a constant coupling of 0.40 second. This is demonstrated by the first extrasystole of Fig. 1,*A*. Warming of the area in which veratrine had been injected 5 minutes and 30 seconds earlier led to the appearance of series of 3 to 7 extrasystoles. The coupling of the first extrasystole of a series is shortened to 0.31 second; the following couplings vary between 0.30 and 0.31. Cooling of the same area abolished series of extrasystoles, and only single extrasystoles appeared. Three single extrasystoles are seen in Fig. 1,*B*. The first one has a coupling of 0.35 second, the second one of 0.37 second, and the third one of 0.42 second.

Fig. 2 was obtained in another experiment in which veratrine at first had provoked a ventricular tachycardia; under the influence of inhalation of carbon dioxide, ventricular extrasystoles with constant coupling appeared after 7 minutes. The first extrasystole in Fig. 2,*A* has, as have all the others, a coupling of 0.42 second. The arrow indicates the beginning of warming of the area on which veratrine had been injected. Here again the number of extrasystoles increases and the coupling is reduced to 0.31 second. The arrow in Fig. 2,*B* indicates the beginning of cooling, a few minutes later. The duration of the coupling of Fig. 2,*B* is 0.34 second; it gradually increases to 0.44 second before the extrasystoles disappear.

The same results were obtained in the other experiments. The coupling shortens on warming and lengthens on cooling the focus of origin of the extrasystoles.

It is interesting to note that, after the extrasystoles disappear due to diminishing effect of veratrine, warming of the area on which veratrine had been injected brings out a bigeminal rhythm (Fig. 3). Fig. 3,*A* and *B* are continuous, with the exception of a small strip of 2 normal beats and 3 extrasystoles which has been removed. The warming had started just before the beginning of Fig. 3,*A* had been registered. It ended at the arrow in Fig. 3,*B*. The coupling of the extrasystoles, which could be elicited only at this time by warming, measured 0.31 second; during the warming it shortened to 0.28 second, and became 0.32 second with the last extrasystole of Fig. 3,*B*.

This reappearance of a ventricular bigeminy during warming of the veratrine focus was reproducible only for 10 to 15 minutes; after this period the veratrine effect disappeared and a new injection was necessary.

DISCUSSION

The coupling of the extrasystoles is usually constant. It does not differ for more than a few hundreds of a second whether the patient is resting or has strenuously exercised, and only rarely is it influenced by drugs; quinidine is known to prolong it. Therefore, any measure or experimental method which modifies its length is of theoretical interest.

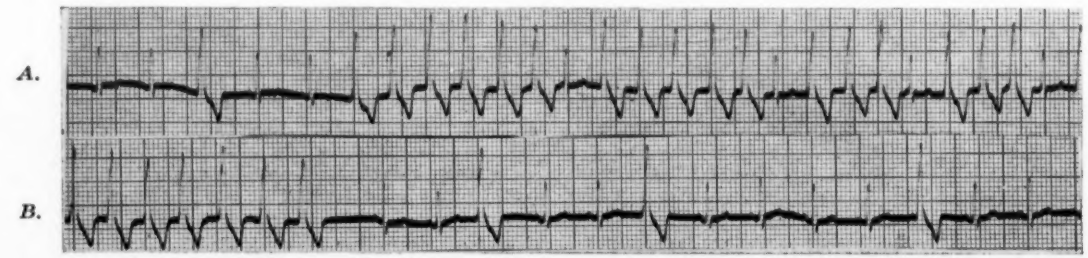


Fig. 1.

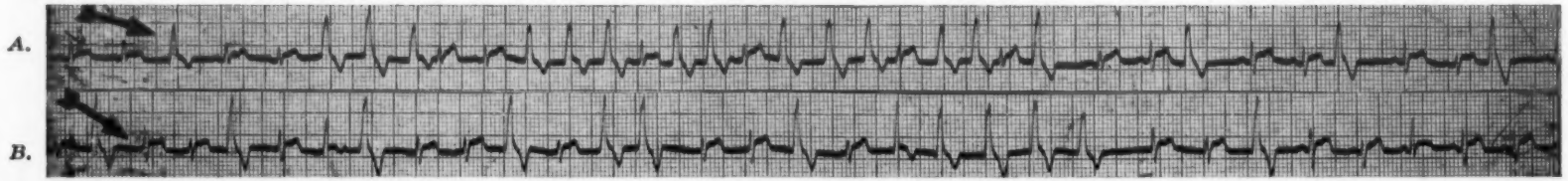


Fig. 2.

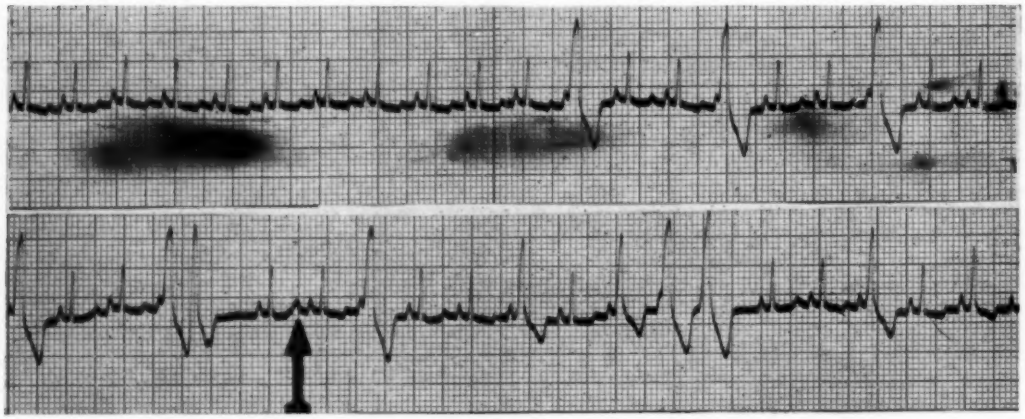
Fig. 1.—After application of veratrine and inhalation of the carbon dioxide-oxygen mixture, ventricular extrasystoles with a coupling of 0.40 second appeared (first part of *A*). Warming the area on which veratrine had been applied started when the extrasystole appeared. This led to an increased number and rate of the extrasystoles and to a shortening of the coupling to 0.30 or 0.31 second. With cooling started at the beginning of *B*, obtained a few minutes later, the extrasystoles diminished and the coupling increased to 0.42 second.

Fig. 2.—Extrasystoles with fixed coupling appeared in this experiment after the same procedure as in Fig. 1. The arrow in *A* indicates the beginning of the warming. This increased the number of extrasystoles, and their rate and the coupling shortened from 0.42 to 0.31 second. There is no parasystole. The arrow in *B* indicates the beginning of cooling. The coupling increased from 0.34 to 0.44 second.

While most students of the mechanism of origin of extrasystoles agree that the fixed coupling indicates that the beat preceding the extrasystole is responsible for it, that it elicits it, opinions differ about the way this is accomplished.

For extrasystoles with fixed coupling, 2 principal mechanisms are discussed. One is the re-entry of the original stimulus of the eliciting beat; there are many modifications of this theory which cannot be discussed here. Although, as mentioned earlier, under special conditions a re-entry mechanism has been proved to exist (reciprocating rhythms, return extrasystoles[5,8]), there is no clinical or experimental proof that re-entry is responsible for the vast majority of clinical extrasystoles. The only experiment often quoted in this connection is that performed by Schmitt and Erlanger[9] on an excised muscle strip of the heart.

A.



B.

Fig. 3.—In this experiment a bigeminal rhythm had existed after the same procedures as in the other experiments and had disappeared spontaneously. Warming the focus of origin of the extrasystoles caused the bigeminy to reappear. The arrow in *B* indicates the end of the warming. Between *A* and *B* a small strip has been removed. The coupling in Fig. 3 is at first 0.31 second, shortens to 0.28, and again reaches 0.32 before the extrasystoles disappear.

The authors concluded from their results that they obtained re-entry impulses, attributable to circumscribed conduction disturbance which they called opisthodromic. These abnormal impulses were later correctly explained as being caused by an after-discharge of impulses (pseudo-reflex of Arvanitaki[1,2]). It should be remembered that the explanation of all extrasystoles by a re-entry mechanism has been only a mere "desk" construction. Even Sir Thomas Lewis knew that the length of the coupling in itself ruled out re-entry as the cause of extrasystoles. The speed of conduction in the heart muscle, on the one hand, and the duration of the coupling, on the other, make this theory untenable. The hypothetical assumption of a conduction disturbance in the re-entry path,[3] for which no experimental basis exists, does not add to the plausibility of the theory.

The results of the experiments discussed above invalidate a re-entry mechanism. Even if one concedes that cooling slows conduction and that warming accelerates it, it could not lead to the lengthening and shortening of the coupling to the degree seen in Figs. 1 and 2.

Several complicated conditions must be present for a re-entry mechanism: According to the hypotheses which assume a circus movement or re-entry, the circus path must have a certain length; the tissue of this path and of the neighboring parts of the heart must have a refractory phase of a certain constant duration; no impulse should reach this path from the opposite, or any other, direction. It is not probable that application of a warming thermode to the area on which veratrine had been injected could always create all these conditions and lead to a bigeminal rhythm as in Fig. 3.

Warming the area in which veratrine had been injected shortened the coupling and increased the rate of the extrasystoles. It is known that the warming of the myocardium increases the rate of conduction; if one assumes a re-entry mechanism, one would expect that with warming the increased speed of the wave would bring the arrhythmia to an end in the following way: the head of the re-entry wave would catch up with the refractory phase at the tail end of the impulse and the propagation of the stimulus would thus stop. This never occurred in the experiments described above. It is true that warming also shortens the relative refractory phase, but it is impossible to explain how the complicated conditions essential to a circus movement could prevail so consistently in a way as never to be interrupted by heat.

The re-entry theories assume that this mechanism takes place in the peripheral twigs of the conduction system. In our experiments, however, the extrasystoles were caused by veratrine applied to the ventricular surface, and, therefore, no specialized tissue could have been involved. A local re-entry movement in the syncytium of the ventricular muscle is highly improbable and is only an assumption without experimental support.

Therefore, we favor the other theory according to which extrasystoles are due to the after-discharge of an impulse in a physically or chemically altered muscle cell ("center"). Such after-discharges, or repetitive firing, of impulses are known to occur in nerve and skeletal muscle, and the works of Arvanitaki and Bozler revealed that this is also true, with only quantitative differences, for the heart muscle. Treatment of a small area of the heart muscle with calcium,[2] withdrawal of calcium by citrate or oxalate, application of veratrine,[1] or mechanical injury of a nerve by crushing[4] may lead to local after-discharge, or to a local increase of the negative after-potential, so that impulses are fired off.

Thus, every cell of the heart is depolarized once, under normal conditions, when an impulse spreads over the heart. If one altered cell is depolarized twice and the local potential reaches a critical value, a propagated impulse follows and an extrasystole appears.[7]

Cooling and warming the focus of origin of extrasystoles, with the respective prolongation and shortening of the repolarization phenomena, will lead, therefore, to variations in the coupling such as described above.

SUMMARY

Extrasystoles with constant coupling are elicited in the dog by topical application of veratrine and the inhalation of 20 per cent of carbon dioxide with 80 per cent oxygen.

Warming the focus of origin of the extrasystoles shortens, cooling lengthens, the duration of the coupling. After the extrasystoles disappear, they are brought out again in the form of bigeminal rhythm by warming the area on which veratrine has been applied.

In the opinion of the authors, these results are best explained if one assumes that extrasystoles are caused by the phenomenon of after-discharge in an altered cell.

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AN EXPERIMENTAL STUDY OF MULTIPLE DIPOLE POTENTIALS AND THE EFFECTS OF INHOMOGENEITIES IN VOLUME CONDUCTORS

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THE living heart has its electrical activity distributed throughout its walls, and its inner compartments are filled with blood having a conductivity 10 times that of the surrounding medium.[1] The standard electrocardiogram is a record of the body surface manifestations of currents generated within the heart volume. The representation of this electrical activity by a single fixed location dipole in a homogeneous medium,[2,3] while useful in designing orthogonal lead systems for vectorcardiography, cannot by itself lead to a correlation between body surface potentials and the active regions of the heart which produce them. Such a correlation can probably be found only by considering the heart as a distributed type generator, and accounting for inhomogeneities which affect body surface potentials.

The dipole is a convenient type of generator to use because of its vector and point location properties. By using a number of dipoles oriented and located to give the best approximation to the actual generator, these desirable properties are retained. Also, since the body medium is linear to a good approximation, the potentials due to multiple dipoles can be calculated by superposition of single dipole potentials.

Thus, while the single fixed location dipole in a homogeneous medium is a first approximation, a more accurate model of the heart can be attained by utilizing multiple dipoles and accounting for the intracavitary blood mass inhomogeneity. This paper concerns itself with the experimental techniques of using multiple dipoles in conducting tanks; the potential distributions created by them; and the effects of inhomogeneities on these distributions.

EXPERIMENTAL CONSIDERATIONS

The generator itself presents the most difficult simulation problem. A Plexiglas hemispherical shell ⅛ inch thick and 4½ inches in diameter was used to mount 33 dipoles. The dipoles were nickel disks 5/16 of an inch in diameter, punched to conform to the hemispherical surface. The outer disks had 2 holes, each ⅛ inch in diameter, drilled in them in order to allow the conducting medium between the plates of the dipoles. The hemisphere was suspended by a Plexiglas rod, ¾ inch in diameter, which carried the 66 exciting wires to the dipole.

This investigation was supported in part by Grant H-339-C, United States Public Health Service.

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Received for publication April 9, 1957.

In order to check the generator against a mathematical dipole, calculated potentials for a radially oriented eccentric dipole were compared to the potentials produced around the circumference of the cylinder by the dipole at the apex of the hemisphere. The formula was derived previously and is given by[4]:

$$V_\rho = \frac{2p_\rho}{ab\pi\gamma} \sum_{n=0}^{\infty} \cos^2\left(\frac{n\pi z'}{a}\right) \sum_{m=0}^{\infty}{}' \frac{\frac{ma}{n\pi\rho'} I_m\left(\frac{n\pi\rho'}{a}\right) + I_{m+1}\left(\frac{n\pi\rho'}{a}\right)}{I_{m-1}\left(\frac{n\pi b}{a}\right) + I_{m+1}\left(\frac{n\pi b}{a}\right)} \times \cos m\,(\phi - \phi')$$

where $\Sigma' = \Sigma\,(1 - \delta_m^\circ)$: $\delta_m^\circ = 0,\ m \neq 0$; $\delta_m^\circ = 1,\ m = 0$

I_m = m th order modified Bessel function of the first kind
ρ, ϕ, z = standard cylindrical coordinates — a = cylinder height
ρ', ϕ', z' = coordinates of dipole location — b = cylinder radius

The sums were carried over m = 5, n = 6 in order to achieve an accuracy of 1 per cent (of the maximum potential difference). The agreement is within 6 per cent of the maximum.

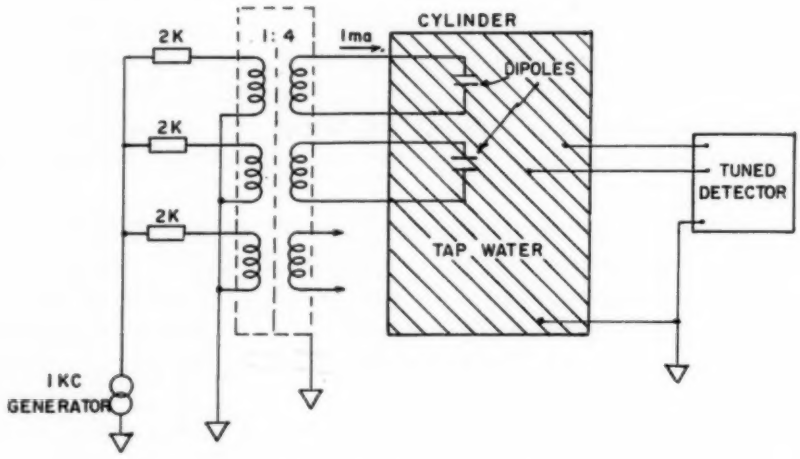

Fig. 1.—Schematic of experimental setup.

Experiments have shown that the generator produces potentials identical, within experimental limits, to single dipole potentials, if a symmetrical array of 4 or more dipoles which have a center of gravity at the location of the single dipole are energized. Thus, there is some assurance that the model behaves like a group of mathematical dipoles, but this should not be interpreted as a comparison between the model and an actual heart.

The driving source was approximately 1 milli-amp at 1,000 c.p.s., with an impedance of approximately 32 kilo ohms, as shown in Fig. 1. The currents in each dipole were adjusted by means of the 2,000 ohm resistors in order to standardize the dipoles. The constant current nature of the source eliminated electrode polarization problems and drift due to changes in the medium conductivity. Each dipole was electrically "floating" by virtue of its own isolation transformer, and its potential relative to ground was determined by grounding an arbitrary point of the medium. Double shielded transformers were used, and the source resistors were placed in the primaries to minimize the effects of coupling due to interwinding capacitance. The effectiveness of these measures was checked by noting the effects on the detector output while varying the ground point over the cylinder surface and also rotating the generator to obtain nulls. The detector changes

and nulls were less than 1 per cent of the maximum boundary potentials. These problems arise when more than one dipole is used in model measurements, since the dipole mid-potential cannot be grounded,[5] and the grounding of one side of a dipole does not solve the problems.[6]

The tuned detector is illustrated with a schematic in Fig. 2. The power supply is gas tube regulated for both + and −150 volts. The input impedance is 1 megohm for the differential input.

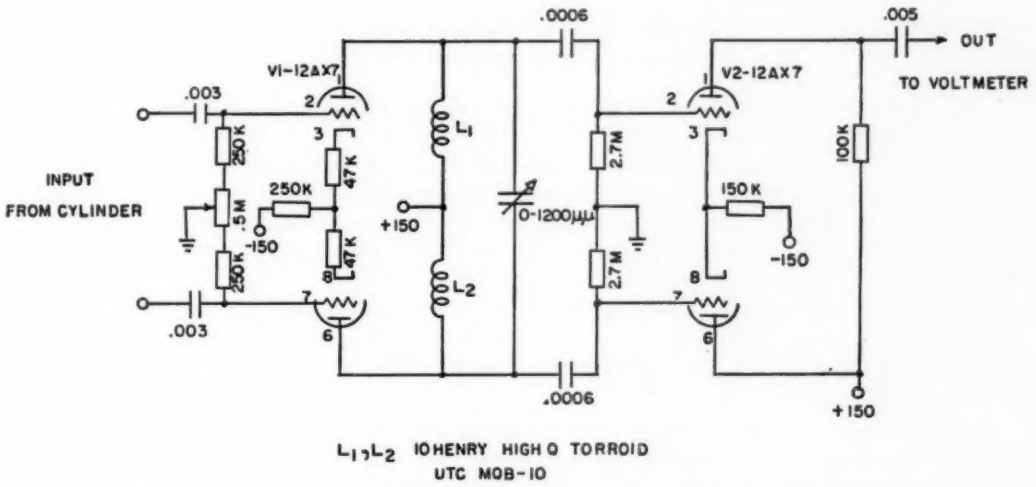

Fig. 2.—Schematic of tuned detector and double-ended to single-ended converter.

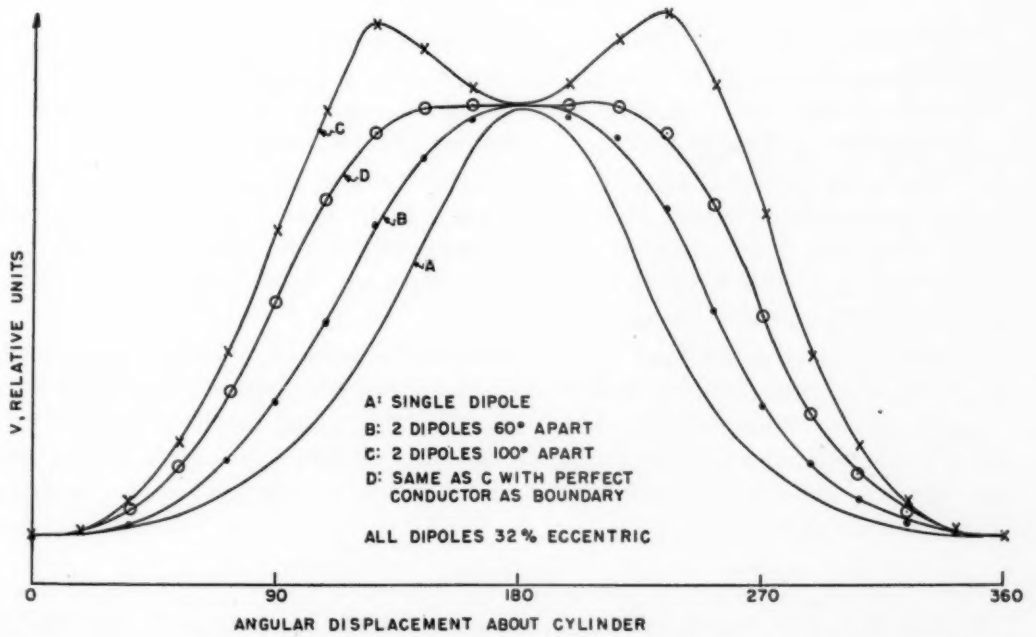

Fig. 3.—Potential distribution around a cylinder at the level of the generator for various modes of excitation.

The first stage is tuned to 1,000 c.p.s., using triodes with large cathode resistors to increase their plate resistance. The Q of the amplifier is 15; 60 cycle rejection is greater than 60 db.; and second harmonic rejection is greater than 30 db. The over-all gain, from double-ended input to single-ended output is 550, and the common mode rejection is greater than 60 db. The potentiometer at the imput is an A.C. balance control which is adjusted for maximum common mode rejection. The second tube is a cathode follower type double-ended to single-ended converter. The output is fed to a Hewlett-Packard VTVM model 400C.

METHOD

The hemispherical generator was inserted into a cylinder filled with tap water. The cylinder was 29 inches high and had a radius of 7 inches. Potentials were measured at the surface for excitation of single dipoles, 2 dipoles, 4 dipoles, and for 2 dipoles with a sheet of metal covering the plane surface of the hemisphere. The sheet of metal was an approximation to filling the inside of the hemisphere with a high conductivity material, as compared with tap water. The effect on the field outside the generator was to make the returning current lines enter the hemisphere normal to its plane surface.

Using standard cylindrical coordinates ρ, ϕ, z with the origin at the bottom center of an upright cylinder, the hemisphere assembly was located at $z = \frac{1}{2}$ of the height of the cylinder and oriented so that the apex pointed in the ρ direction, with the plane surface of the hemisphere along a $\phi =$ constant plane.

Fig. 3 illustrates the potential variations about the cylinder at $z =$ constant ($\frac{1}{2}$ cylinder height), for 2 dipole versus single dipole excitation. The effect of increasing the angular separation between the 2 dipoles is to cause double peaking (which could never be produced by a single dipole). The insertion of the perfect conducting boundary removes the double peaking and causes the potential curve to approach the single dipole curve. The potential due to 4 dipoles symmetrically located about the apex of the hemisphere coincided, within experimental limits, with the single dipole potential.

DISCUSSION

The results indicate that large errors are inherent in neglecting the separation between 2 dipole sources for computing surface potentials. Thus, the representation of each ventricle by its own fixed location dipole cannot be used to explain surface potentials without considering their separate locations.[7]

Potentials produced by a symmetrical array of 4 or more dipoles are very similar to single dipole potentials. Previous work by Frank[8] on a uniform double layer source has shown that the resulting potentials can be closely duplicated by a single dipole. The 4 dipole symmetrical array can be looked upon as a good approximation to the uniform double layer.

Brody[9,10] has shown that a high conductivity mass significantly distorts the heart lead relationship for simple theoretical models, and he has conducted experiments on 2 dimensional models to verify this. The results presented here for a 3 dimensional model are in agreement with his conclusions, and further suggest that the blood mass in the heart may contribute to the accuracy of the single dipole representation.

SUMMARY

A technique is described for taking measurements in a 3 dimensional medium excited by more than 1 current dipole. A hemispherical multiple dipole assembly was constructed and used to excite a cylindrical tank filled with tap water.

Potentials produced by 2 dipoles differ considerably in magnitude and shape from those produced by an equivalent single dipole. Two eccentric dipoles, if separated enough, produce double peaked potential curves which are impossible to duplicate by any single equivalent dipole. An attempt to simulate the effects of a high conductivity mass inside the generator by a perfect conducting sheet is described.

The conducting sheet has a strong effect on the surface potentials, and when used in conjunction with 2 dipoles it produces potentials which approach single dipole ones.

It should be understood that the model described here is not claimed to represent accurately the electrical activity of the heart. The purpose of this study has been rather to investigate the manner in which multiple dipole sources produce surface potentials in a 3 dimensional medium, and the effects on these potentials by inhomogeneities close to the sources.

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THE PRESSURE EVENTS OF THE CARDIAC CYCLE IN THE DOG: AORTIC VALVE LESIONS

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THE purpose of this report is to illustrate the application of simultaneous and equisensitive pressure pulse recording to experimentally produced aortic valve lesions. This technique permits direct analysis of the instantaneous relationship of aortic, left ventricular, and left atrial curves at any point in the cardiac cycle, making unnecessary retracing or superimposition of separately recorded curves.[1,2] Synchronous events in the separate cardiac chambers are more easily analyzed from curves obtained by this method.

Pressure tracings were obtained by direct puncture of the left heart chambers of dogs with stenotic and insufficiency lesions of the aortic valve. In addition, the transformation of the contour of the central aortic pulse into the peripheral arterial curve in dogs with single and combined aortic valve defects was studied by simultaneous needle puncture of the aortic arch, descending aorta, and femoral artery. The manner in which the superimposition of aortic stenosis on an insufficient aortic valve modifies the central and peripheral arterial pressure pulse was studied.

METHOD

Adult mongrel dogs averaging 18 kilograms in weight were anesthetized with intravenous Nembutal, 30 mg. per kilogram. Positive pressure respiration was maintained with 100 per cent oxygen supplied by a pneophore demand valve at a pressure of 10 to 15 cm. of water. The pericardium was opened through a left thoracotomy and sutured to the chest wall, forming a loose hammock support. A nerve hook was introduced through the left ventricular wall and directed up into the aorta. Aortic insufficiency was produced when one aortic cusp was caught and partially avulsed as the nerve hook was withdrawn. Aortic stenosis was simulated by constricting the root of the aorta with a heavy linen tape at a level just above the valve cusps. Contrary to the situation in aortic stenosis as it occurs in the human being, the coronary artery ostia are proximal to the constricting ligature in this type of experimental aortic stenosis.

Pressure pulses were obtained in 29 dogs by direct puncture of the left atrium, left ventricle, aorta, and femoral artery with 1½ inch 20 gauge needles attached to 122 cm. lengths of noncompressible vinyl tubing. Pressures were led into 3 matched Statham P 23 A or P 23 D strain gauges. Curves were recorded at equal sensitivity from a common base line, together with electrocardiographic Lead II on a 4-channel oscillographic recorder, at a paper speed of 50 or 75 mm. per second. Time lines permitted measurement to the nearest 0.01 second.

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RESULTS

1. *The Pulse Contours in Aortic Stenosis.*—Representative pressure curves of the left atrium, ventricle, and aorta in aortic stenosis are illustrated in Fig. 1.

The aortic pressure pulse, following the acute constriction of the root of the aorta, is characterized by an abbreviated steep systolic upstroke ending in an anacrotic notch low on the ascending limb, a further slow ascent to a delayed peak, and the presence of systolic vibrations due to highly turbulent flow superimposed on the aortic curve.[3] The aortic pulse pressure diminishes primarily because of a fall in systolic pressure, and the dicrotic incisura becomes blunted. With increasing degrees of stenosis, the anacrotic notch may virtually disappear from the aortic curve, but an inflection on the ascending left ventricular limb can still be detected.

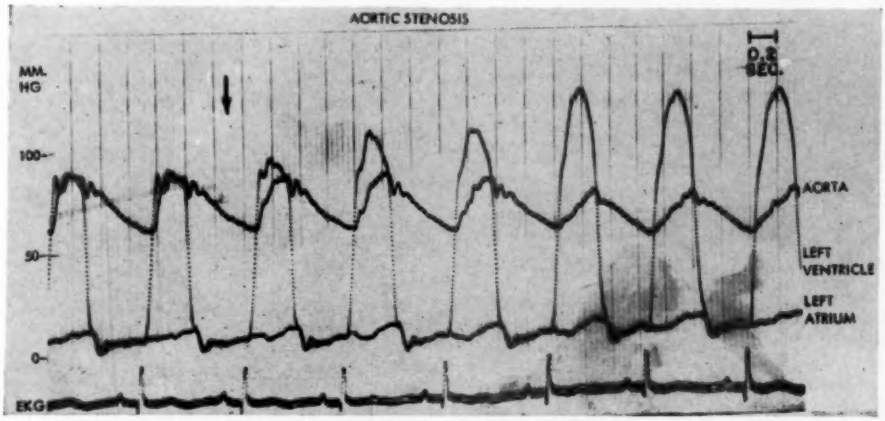

Fig. 1.—Simultaneous and equisensitive pressure pulses from a dog's left atrium, left ventricle, and aorta during the acute production of aortic stenosis. The arrow designates the onset of aortic root constriction. Paper speed 50 mm./sec.

Distinctive changes occur in the left ventricular pulse during aortic stenosis. The anacrotic shoulder, which characterizes the ascending limb of the normal left ventricular tracing, becomes less pronounced during the stenosis and reappears as the aortic constriction is released. The left ventricular curve acquires a sharply peaked configuration in aortic stenosis,[3] closely resembling the contour of the right ventricular pulse in pulmonic stenosis[4,5] or the "isometric contraction" curve of the left ventricle during frustrate premature beats. A systolic gradient of pressure appears between the left ventricle and aorta in aortic stenosis. The magnitude of the gradient is dependent both on the degree of constriction of the aortic orifice and on flow.[6,7]

The transformation of the central aortic pulse into peripheral arterial curve during aortic stenosis is represented in Fig. 2.

Frictional resistance and distensibility of the arterial bed tend to smooth and damp the peripheral arterial pulse contour, while reflected waves lead to distortion.[8] It can be seen from Fig. 2 that in the normal and in aortic insufficiency the ascending limb of the pulse curve grows progressively longer and

the anacrotic notch appears in a higher position or becomes a primary peak as the pulse travels from aorta to femoral artery. However, when aortic stenosis is superimposed on the normal or on an insufficient aortic valve, the initial upstroke remains short and the anacrotic notch retains a relatively low position, as the central pulse moves peripherally. The peak femoral artery systolic pressure in the normal and in aortic insufficiency exceeds the central aortic systolic pressure by about 20 per cent, but when aortic stenosis is superimposed, this difference decreases to approximately 5 per cent.

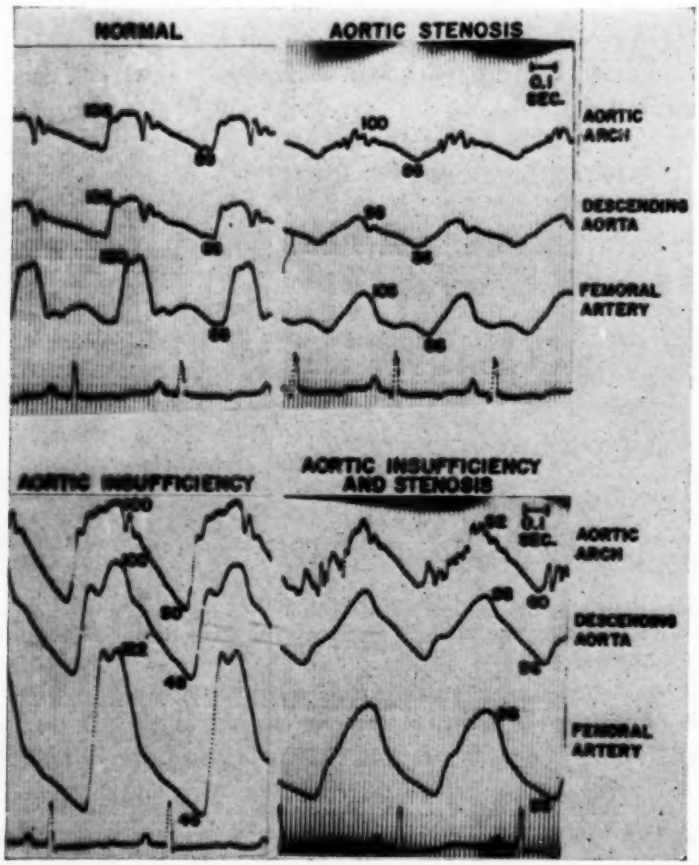

Fig. 2.—The transformation of the central into the peripheral pulse in the normal, in aortic stenosis, in aortic insufficiency, and in combined aortic insufficiency and stenosis. Paper speed 75 mm./sec.

2. *The Pulse Contours in Aortic Insufficiency.*—A representative illustration of the pressure pulses of left atrium, ventricle, and aorta following the acute production of aortic insufficiency is shown in Fig. 3.

The characteristics of the pressure pulse in aortic insufficiency are a very steep rise to an early peak, due to the high velocity of the ejected blood, a steep fall in pressure with a lowered or absent dicrotic incisura, and a widened pulse pressure. At times a double-peaked or bisferious summit is present.[10,11] The isometric contraction phase of the ventricular pulse is shortened because of a

lowered aortic diastolic pressure. During ejection the pressure in the ventricle rises in a fashion parallel to that of the aortic curve, with no detectable systolic gradient between the two. The slope of left ventricular pressure decline is unaffected, unless the aortic leak is of huge size.[12]

The early collapse of the insufficient aortic pulse appears to be due largely to increased runoff at the periphery, since this takes place during the latter part of systole while the ventricle is still ejecting blood. This may not be the entire explanation, and Alexander[13] postulates that the leak produced by aortic insufficiency in the normally closed aortic compression chamber serves to alter its resonance in a fashion similar to certain other clinical conditions characterized

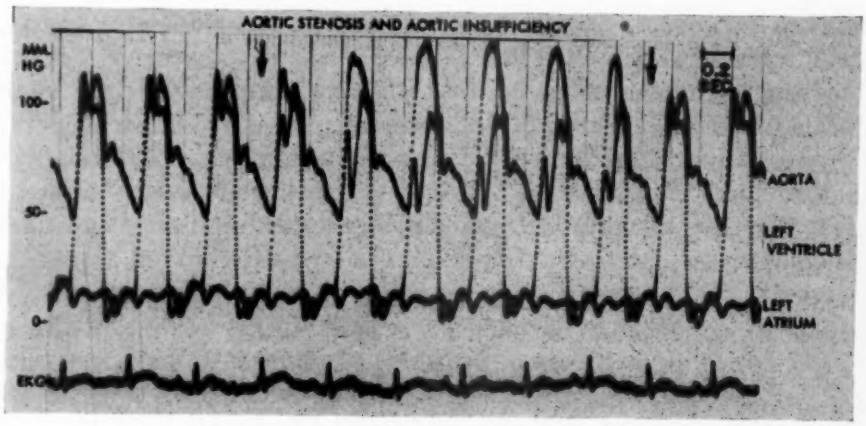

Fig. 3.—The pressure pulses of the left heart in a dog with aortic insufficiency. Aortic stenosis is superimposed on the insufficient valve at the first arrow, and released at the second arrow. Paper speed 50 mm./sec.

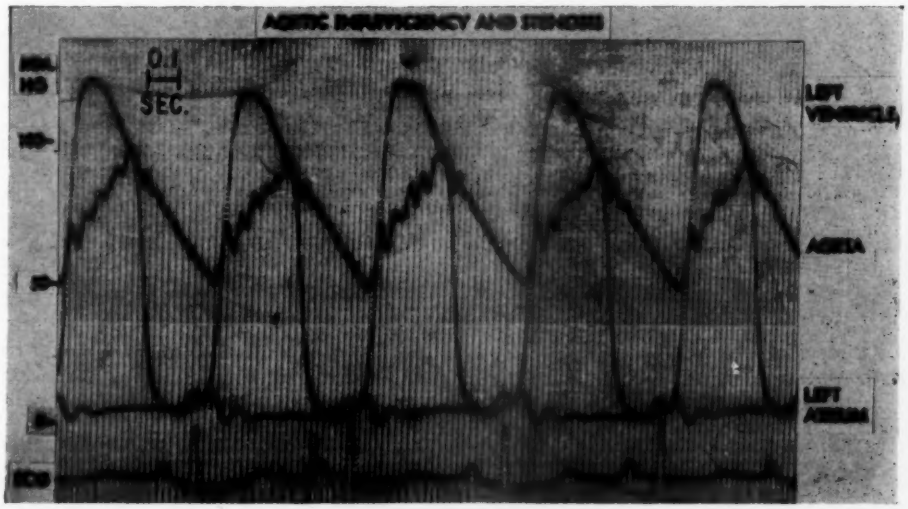

Fig. 4.—Equisensitive pressure pulses in a dog with combined aortic stenosis and insufficiency. Paper speed 75 mm./sec.

by vasodilation or rigid arterial walls. Comparable brachial artery tracings can be recorded under conditions of increased systolic discharge associated with low peripheral resistance, such as fever, anemia, or thyrotoxicosis, or when atherosclerosis decreases the distensibility of the arterial bed.[14]

3. *The Pulse Contours in Combined Aortic Stenosis and Insufficiency.*—Pressure pulses obtained from the left atrium, ventricle, and aorta of dogs with acutely created, combined aortic lesions are shown in Figs. 3 and 4.

The combined lesion of aortic stenosis and insufficiency is usually dominated by the features of aortic stenosis.[15] The aortic pulse pressure narrows as the systolic pressure declines and a slight rise in diastolic pressure takes place. In the combined aortic lesion, the features of free regurgitation are masked despite the fact that the aortic leak is still present, and can be demonstrated by cardioangiographic studies of this combined lesion.[16] An entire series of aortic curves can be produced, ranging from the true water-hammer pulse to the slow rising blunt peak with marked anacrotism, depending on whether stenosis or insufficiency predominates.[10] Although many of the contour characteristics of the incompetent aortic curve are obscured by coexisting stenosis, the retention of a relatively low diastolic pressure appears to be a significant diagnostic indication that insufficiency is present.

The transformation of the central aortic into the femoral arterial pulse in combined aortic stenosis and insufficiency is shown in Fig. 2.

4. *The Pulse Contours in Aortic Constriction or Coarctation.*—An example of simultaneous, equisensitive pulse recording during constriction distal to the aortic root is shown in Fig. 5.

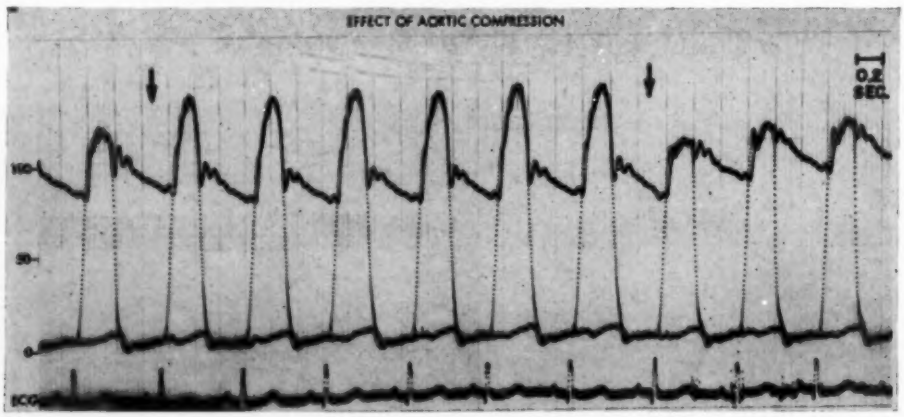

Fig. 5.—Equisensitive pressure pulses during simulated coarctation of the ascending aorta. The ligature is tightened at the left arrow and released at the arrow on the right. Paper speed 50 mm./sec.

Proximal to the coarctation, the pulse pressure widens, primarily because of a rise in left ventricular and aortic systolic pressures, while aortic diastolic pressure falls or remains unchanged. The aortic curve shows a prominent systolic collapse to a lowered dicrotic incisura. These changes are due apparently to a reduction in size of the aortic compression chamber, the walls of which be-

come less distensible as they are placed under greater stretch, and a concomitant rise in left ventricular systolic discharge.[17] Proximal to the constriction, the communicating ventricle and aorta demonstrate synchronous anacrotic vibrations which are less pronounced than in the normal curves.

DISCUSSION

The genesis of normal anacrotic phenomena and the accentuated anacrotic notch seen in aortic stenosis have been the subject of varied interpretation in the literature. The normal aortic pressure pulse displays a rapid initial upstroke to an anacrotic shoulder which is usually accompanied by a synchronous inflection on the left ventricular curve. At times, this upstroke may become accentuated to form an early peak due to the momentary water-hammer fling of blood, if the arterial system is underfilled.[18] Peterson[19] suggests that the anacrotic notch may be the point of momentary deceleration of blood when velocity energy appears as pressure energy. Wright and Wood[9] state that this anacrotic pause is actually the early peak of a double wave in the normal aortic pulse, and that it is this early wave which becomes accentuated to form the systolic peak in the peripheral arterial curve. This would explain the illusion that the foot of the transmitted pulse travels more rapidly than its peak.

In aortic stenosis, Katz and associates[3] postulate that the suction effect of the swift axial stream beyond the constriction is responsible for the pronounced anacrotic vibration. Dow[20] states that the anacrotic incisura in aortic stenosis is caused by the sudden breakdown of smooth flow into turbulence. According to Hull[21] the anacrotic notch marks the point when ejection velocity falls off in response to the increased resistance to flow produced by the initial rapid discharge that follows the sudden opening of the stiffened aortic valve. Allan,[22] on the other hand, points out that the velocity through the narrowed orifice is markedly increased, and others[3,23,24] attribute the sudden fall in lateral pressure beyond the stenosis to the marked increase in velocity of flow as the lateral pressure energy is converted into kinetic energy. The Scandinavian workers refer to this phenomenon as "the depressor effect of the pressure of velocity."[4]

Peterson[25] attributes the rapid initial upstroke of intra-aortic pressure preceding the anacrotic pause to the systolic acceleration of blood rather than purely to the reluctance of arterial walls to stretch,[26] since it can be demonstrated in vessels whose walls are not stretched by increasing internal volume. It is of some interest in this connection that in pulmonic stenosis the pulmonary artery curve is characterized by a short, initial steep rise, followed by a systolic dip which corresponds to the anacrotic notch of aortic stenosis.[4] This systolic dip in the pulmonary artery curve of pulmonic stenosis becomes damped as the pulse travels to the periphery, in a fashion similar to the loss of clarity of the anacrotic notch that occurs as the pressure pulse in aortic stenosis moves peripherally.

The location of the anacrotic shoulder on the normal aortic curve depends on the velocity of systolic discharge, the elasticity of the walls of the arterial tree, the peripheral resistance, and the degree to which the arteries are filled with distending blood. Thus, with a poorly filled arterial system, the anacrotic pause is accentuated to form a primary peak or fling in the normal aortic pulse, or a

bisferious pulse in aortic insufficiency. With hypertension or coarctation, the anacrotic pause is minimal. In aortic stenosis, the anacrotic notch is displaced downward and becomes markedly accentuated by the extreme turbulence and high velocity of flow beyond the stenotic orifice. In combined aortic valve lesions, the anacrotic notch will be present if stenosis predominates, or it will represent a reduced early peak of a bifid curve if insufficiency is the dominant lesion. The anacrotic inflection occurs as a synchronous and superimposable event in the aorta and left ventricle in the normal, in aortic hypertension, and in aortic insufficiency. In aortic stenosis, the anacrotic vibrations on aortic and left ventricular curves remain synchronous, but are separated by a pressure gradient. The common denominator of all these early systolic pauses is an abrupt change in slope of ascending pressure during initial ejection. At this anacrotic inflection, the steep acceleration effect on an unyielding aortic compression chamber is succeeded by a more gradual distending effect of ejected blood on aortic walls that are now beginning to give more readily. The magnitude of this volume gain due to ejection is modified by the degree and rapidity of peripheral runoff.

SUMMARY

1. The technique of simultaneous equisensitive pulse pressure recording was applied to a group of 29 dogs in which aortic stenosis, aortic insufficiency, combined aortic stenosis and insufficiency, and aortic coarctation were acutely created. In addition, the transformation of the central into the peripheral pulse in these lesions was studied.

2. The effect of superimposing stenosis on normal and insufficient aortic pulses was to narrow the pulse pressure, delay the systolic peak, and produce a prominent anacrotic notch in a lowered position on the ascending limb. The contour characteristics of aortic insufficiency were dominated and masked by the superimposed stenosis, although the maintenance of a low diastolic pressure indicated that insufficiency was present.

3. As the normal central pulse was transformed into the peripheral, the anacrotic shoulder rose to become a primary peak. In aortic stenosis, however, the anacrotic notch retained its low position on the ascending limb, although its features became less clear as the central pulse moved peripherally.

4. The anacrotic notch or pause was a synchronous and superimposable event on the aortic and ventricular pulses in the normal, in aortic insufficiency, and in aortic coarctation. When aortic stenosis was produced alone or in combination with aortic insufficiency, the anacrotic notch on the aortic curve was separated from a synchronous vibration on the ventricular curve by a pressure gradient.

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AN EXPERIMENTAL STUDY OF BLOOD FLOW IN NEUROGENIC HYPOTENSION AND HEMORRHAGIC SHOCK

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WHETHER there is a fundamental difference between the physiologic mechanism of neurogenic hypotension or "shock" and that of hemorrhagic shock is a debated subject of considerable clinical importance. If, indeed, the neurogenic variety is the reduction of peripheral vascular resistance by the obliteration of arteriolar spasm or tone, then maintenance of normal or near-normal blood flow might reasonably be expected, depending on maintenance of the cardiac output.[1] Sympatholytic drugs, nerve blocks, and operations are known to produce a hypotensive state usually characterized by a slow, regular heart rate and warm dry extremities. Such patients are notably lacking in the classical apprehension, restlessness, pallor, and cold moist skin of hemorrhagic or "surgical" shock. The former state in most instances is controllable, reversible, and characterized by clinically normal or near-normal function of the vital organs.[2] Thus it can be inferred from clinical evidence that visceral flows are not seriously impaired even at low pressures which might be comparable to those of irreversible hemorrhagic shock.

Experimental evidence of increased flow rates and decreased peripheral vascular resistance resulting from sympatholytic drugs has been presented by various workers.[3-7] The safety of hypotensive anesthesia has been demonstrated repeatedly and the technique has gained wide clinical application.[8-11] Wiggers[12,13] and others[14,15] have shown that Dibenamine exerts a protective effect in preventing death from hemorrhagic shock. Their data suggest that sympathetic denervation may result in the maintenance of essential blood flow even at very low pressures.[16] This indirect evidence of disproportion between arterial pressure and apparent blood flow in certain states led to investigation of flow rates in various types of hypotension.

MATERIALS AND METHOD

Healthy mongrel dogs weighing 15 to 25 kilograms were premedicated with morphine sulfate, 2.5 mg. per kilogram, and lightly anesthetized with intravenous sodium pentobarbital. Total heparinization was accomplished with 6 to 8 ml. of heparin just before the cannulae were inserted.

The animals were placed horizontally in the left lateral decubitus position. The left femoral and right common carotid arteries were exposed and doubly cannulated in series to bubble flowmeters (Fig. 1). These were low-resistance, short, polyethylene coils with an inside diameter of

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Supported by the Hendry Fund for Medical Research.

Received for publication April 22, 1957.

2.92 mm., which closely approximated that of most arteries cannulated. Flow rates were determined by injecting an air bubble of 0.1 c.c. through a rubber-capped side arm, measuring its traverse time and using the mean of 3 observations. Simultaneous pressure readings were obtained with an attached strain gauge and recording oscillograph. The effect of these small peripheral air emboli did not appear to be significant; serial flow rates under stable conditions were reasonably consistent, but when repeated in rapid sequence there was some slowing suggestive of transient peripheral arteriospasm. Flowmeter resistance was determined at various pressures and peripheral (mechanical) resistances; it was found to be roughly constant when expressed as the percentage of the flow rate without flowmeter in place. The character and magnitude of these variables produced quantitative inaccuracies in flow rate values but relative changes were reliably observed. When expressed against accurate pressure determinations, valid comparisons of apparent peripheral resistance changes can be evaluated.

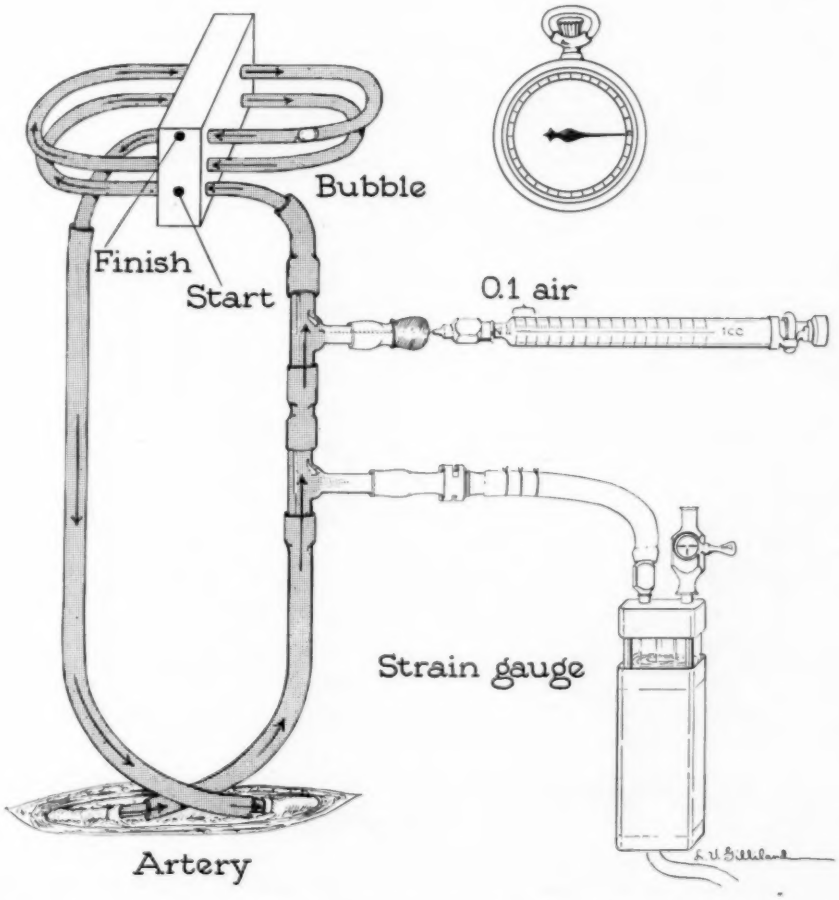

Fig. 1.—Diagram of bubble flowmeter used to determine blood flow in dogs. Coil capacity is 5.6 ml.

Three groups of dogs were studied for comparative effects of different hypotensive states on blood flow to the head and to an extremity. Control observations were made before inducing hypotension, and in most instances these levels of both pressure and flow were restored at the end of the experiment, using reinfusion after bleeding and vasopressors after sympathetic denervation. There was no evidence of clotting, in either the cannulated vessel or the flowmeter, in any of the experiments included in this report.

Animals in Group 1, labeled "Hemorrhage," were progressively bled to hypotensive levels averaging a 60 per cent drop in median arterial pressure from control values.

A second group of experiments, whose data is not tabulated, represented an effort to accomplish total sympathectomy[17] by transection of the spinal cord at the level of the eighth cervical vertebra. Early attempts at intrathecal injection had failed to produce consistent pressure drops and a trial was made to produce hypotension by this alternative technique. This method was later abandoned because the decline in pressure was not satisfactory. In 8 autopsy-proved complete cord sections the pressure reduction was only 29 per cent, which failed to reproduce Phemister's experience with an average reduction of 57 per cent, using the same method.[18]

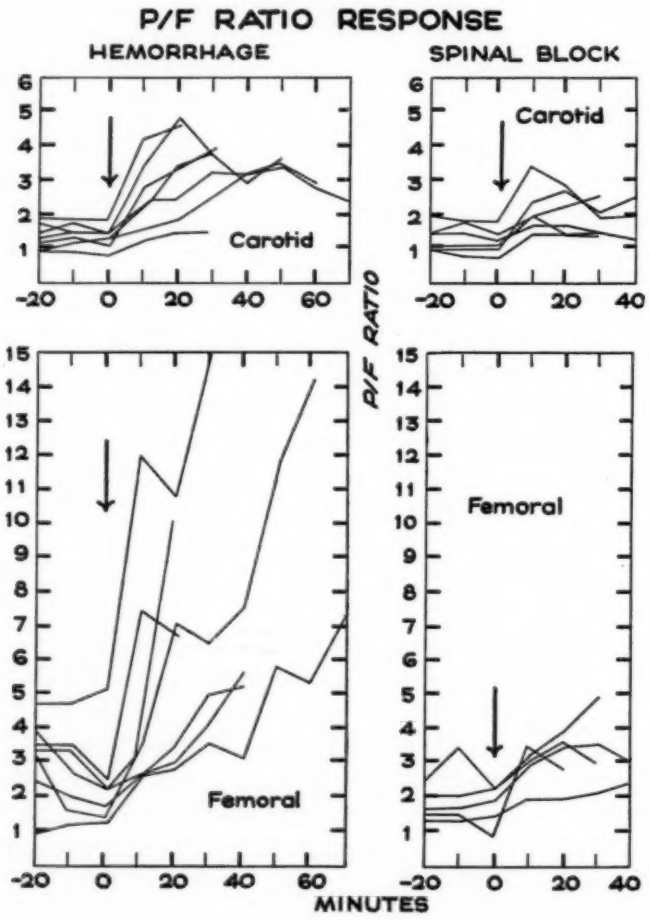

Fig. 2.—Graphs showing the P/F ratio response in the carotid and femoral arteries after hemorrhagic shock and spinal hypotension.

Dogs in Group 3, labeled "Spinal," were successfully given a high spinal blockade with procaine solution introduced into the subarachnoid space in the upper dorsal region. The solution was introduced through a fine (1.8 gauge, Fr. scale) polyethylene catheter which was threaded cephalad through a No. 18 spinal needle inserted intrathecally into the fourth lumbar intervertebral space. Total intercostal paralysis was produced in every experiment and, frequently, artifical respiration was required when diaphragmatic paralysis also occurred. Median arterial pressures averaged 47 per cent of control values.

RESULTS

Satisfactory and clinically significant drops in blood pressure were consistently obtained in Groups 1 and 3. Associated changes in flow rates were observed to be directly related to blood pressure regardless of the cause of hypotension. Although average flow values were distinctly different in the neurogenically induced hypotension from those in hemorrhagic shock, the differences did not suggest a reversal of physiologic response. Average maximum flow decreases were 63 per cent in Group 3 (Spinal) and 85 per cent in Group 1 (Hemorrhage); however, at very low flow rates the accuracy of measurement is unreliable. Considerable variation with overlapping results was encountered in each group; in no instance was flow maintained at or near control levels when pressure dropped.

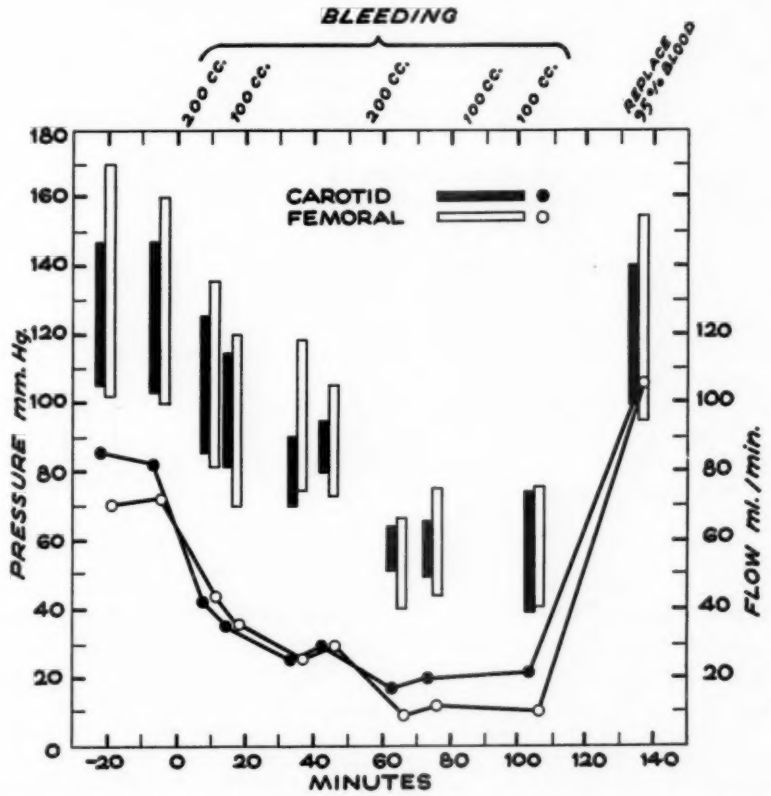

Fig. 3.—Graph of a typical response of blood flow and blood pressure in a dog subjected to hemorrhage.

"Peripheral resistance" was evaluated in the form of P/F ratio which provided the only valid basis for comparison between the different groups. A rise in P/F ratio indicated a greater decrease in flow than in pressure, with maintenance of blood pressure at the expense of blood flow. As expected, there were significant P/F rises following hemorrhage, averaging 131 per cent over control values in the carotid artery and 288 per cent in the femoral artery.

According to established theory the peripheral resistance should be reduced after sympathetic denervation. In these experiments, however, it was found that

instead of falling all femoral P/F ratios rose, with an average increase of 136 per cent. Most of the carotid P/F ratios rose, with an average of 56 per cent above control values, although there were minor resistance drops of 7 per cent, 8 per cent, and 9 per cent, respectively. Fig. 2 summarizes the pattern of resistance change which occurred in each group of experiments with each artery. As expected in each group the femoral resistance was increased more than the carotid resistance, but there is no evidence to suggest that resistance is significantly reduced in one group and increased in the other.

The tabulated observations (Tables I and II) are those at minimum pressure levels; serial data were obtained in each experiment and subsequently plotted.

TABLE I. BLOOD PRESSURE AND BLOOD FLOW DROP IN HEMORRHAGIC SHOCK

ARTERY	PRESSURE (MM. Hg)	FLOW (MM./MIN.)	RESISTANCE CHANGE (P/F RATIO)
Carotid			
Greatest Change	146/104 to 55/30 (66%)	111 to 14 (87%)	+202%
Least Change	134/92 to 84/76 (43%)	96 to 22 (77%)	+90%
Average Drop	systolic = 56% diastolic = 61% median = 59%	82%	+131%
Femoral			
Greatest Change	200/125 to 45/45 (72%)	89 to 5 (94%)	+530%
Least Change	140/90 to 76/46 (49%)	60 to 10 (83%)	+142%
Average Drop	systolic = 62% diastolic = 52% median = 61%	90%	+288%

Figures in parentheses indicate median values.

TABLE II. BLOOD PRESSURE AND BLOOD FLOW DROP IN SPINAL HYPOTENSION

ARTERY	PRESSURE (MM. Hg)	FLOW (MM./MIN.)	RESISTANCE CHANGE (P/F RATIO)
Carotid			
Greatest Change	164/116 to 74/46 (57%)	72 to 12 (83%)	+172%
Least Change	140/55 to 85/50 (30%)	71 to 48 (32%)	− 9%
Average Drop	systolic = 39% diastolic = 49% median = 44%	74%	+ 56%
Femoral			
Greatest Change	132/64 to 36/20 (71%)	33 to 3 (91%)	+450%
Least Change	158/96 to 101/55 (39%)	60 to 22 (63%)	+ 32%
Average Drop	systolic = 51% diastolic = 53% median = 52%	54%	+136%

Figures in parentheses indicate median values.

Although in each instance smooth curves were obtained, the magnitude of change varied from animal to animal. The absence of significant divergence between pressure and flow curves at any point indicates that changes in the peripheral resistance in these experiments failed to compensate for the hypotensive effect of sympathetic denervation. Figs. 3 and 4 demonstrate a typical curve for each type of hypotension.

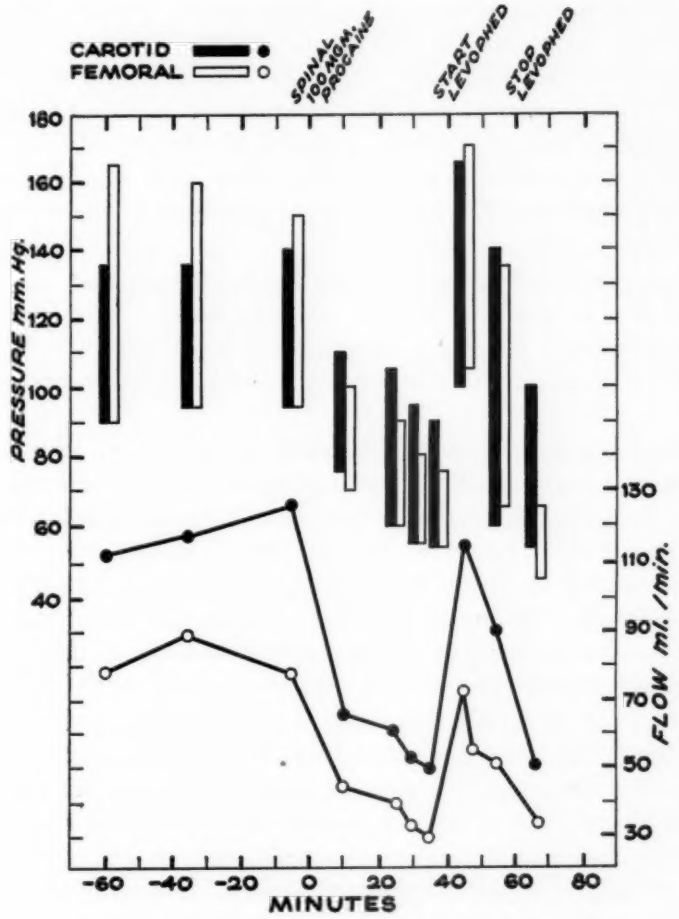

Fig. 4.—Graph of a typical response of blood flow and blood pressure in a dog subjected to spinal hypotension.

It is apparent that the effect of sympathetic denervation on peripheral vascular flow is similar in many respects to that of actual reduction in blood volume. Our experiments would suggest that peripheral resistance as indicated by major artery flow is not reduced in the former state; therefore, by deduction, it must be concluded that pressure changes are a function of cardiac output. Effective circulating volume may be reduced by venous pooling which decreases venous return and thus causes a drop in cardiac output. The importance of gravity in maintaining venous return in spinal hypotension has been emphasized and lends further support to the venous pooling concept.[19-23] Perhaps the variable reports

on flow studies elsewhere are related to variations in postural venous drainage. The pooling phenomenon can provide protection against excessive blood loss. Freeman[24] discovered that the ability to survive with lowered arterial pressures after sympathectomy was accompanied by less tolerance to blood loss. The data of Wiggers[12] indicate that his dogs, when protected with Dibenamine, retained considerably more blood than the controls at the same pressure level. Rovenstine[25] demonstrated a decreased cardiac output but no significant decline in total peripheral resistance in high spinal anesthesia in the human patient. Smith and associates[26] showed wide variations in renal blood flow in the denervated kidney at constant pressures; they pointed out that decreased venous pressure, lowered cardiac output, and increased A-V oxygen differences would indicate that venous, rather than arteriolar, dilatation is the cause of a drop in pressure. Lynn and associates[27] found a significant drop in cardiac output, tissue oxygen consumption, and left ventricular work under spinal hypotension. They postulated a lowered tissue metabolism with less ischemia than might result from reduced blood flow otherwise. Morris and associates,[4] using the nitrous oxide desaturation technique[28] showed a significant (30 per cent) decrease in cerebral blood flow, with a 38 per cent reduction in pressure induced with hexamethonium bromide.

This evidence is at variance with other clinical and experimental observations. Stone and his co-workers,[29] also using the nitrous oxide method, showed no significant change in cerebral blood flow or metabolism after a 44 per cent drop in pressure. Burch and Harrison[30] showed that in spinal anesthesia the cardiac output is reduced after the blood pressure drop, suggesting a lowered resistance.

Expansion of the peripheral vascular bed (or reservoir) with concomitant pressure drop has classically been interpreted as evidence of decreased resistance. However, without flow measurements this is not necessarily valid, since it can occur also with fixed arteriolar diameter, venous pooling, and decreased cardiac output. Evidence has been presented from this study to show that peripheral resistance is increased, suggesting preservation of spastic reflex changes in neurogenic hypotension as well as in hemorrhagic shock. What effect this apparent resistance has on capillary circulation is not determined and our measurements of flow may not reflect the actual tissue blood supply. Undoubtedly, various degrees of arteriovenous shunting take place and are not determined by this technique.

SUMMARY

Contrary to established doctrine of blood flow, our experiments demonstrated a significant decrease in flow rate with sympathetic denervation. Explanation of the difference between the clinical state of neurogenic hypotension and hemorrhagic shock must be explained on a basis other than maintenance of normal flow.

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HIGH OUTPUT FAILURE FOLLOWING ARTERIALIZATION OF THE CORONARY SINUS

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INTRODUCTION

THE objective in the surgical treatment of coronary artery atherosclerosis is the correction of the imbalance between the existing blood supply and the nutritional demands of the myocardium.

Following the initial suggestions of Robert,[1] Beck[2-5] devised a method of establishing retrograde arterial blood flow from the ascending aorta to the coronary sinus by means of a vascular graft. This served to direct oxygenated blood to the capillary system through the venous channels. Theoretically, the full thickness of the myocardium could be revascularized even though significant occlusive arterial disease was present.

This communication details the remarkable pathophysiologic and clinical consequences which ensue when the fistula established between the aorta and coronary sinus is larger than necessary. In addition, it outlines the prompt relief from congestive heart failure which occurs when the abnormal communication is closed surgically.

CASE REPORTS

CASE 1.—C. T., a white man 49 years of age, developed coronary insufficiency due to atherosclerosis, in 1937. His symptoms became gradually more severe, until admission to the Hahnemann Hospital, in May of 1953, at which time he was unable to engage in productive activity. Approximately 12 tablets of nitroglycerin (gr. 1/100) were required to keep him free of pain during the waking day. There was no history of decompensation. Physical examination revealed no abnormality. Blood pressure was 150/90 mm. Hg. X-ray examination (Fig. 1,*A*) revealed a 1 to 2 plus enlargement of the left ventricle. The electrocardiographic examination revealed left ventricular hypertrophy and associated myocardial damage. The hemoglobin was 13.6 Gm. per cent. The hematocrit was 47 per cent. The blood sedimentation rate was 15 mm. in 1 hour. The blood urea nitrogen was 17 mg. per cent, and the fasting blood sugar was 89 mg. per cent. The blood Wassermann was negative. Because of the patient's progressive incapacitation, he was approved for coronary sinus arterialization.

During the second stage of the operation, the size of the opening into the coronary sinus was believed to have been reduced to 3 mm. However, within 24 hours the patient developed acute left ventricular failure. He responded to digitalization and salt restriction and was discharged ostensibly well.

Received for publication May 7, 1957.

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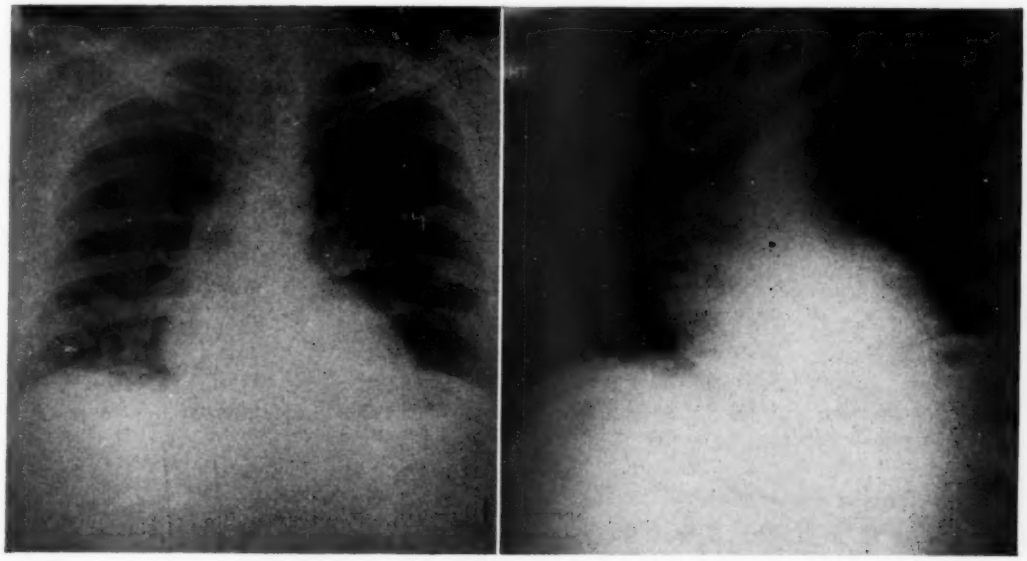
The patient was readmitted to the hospital, in December, 1954, because of heart failure. The heart size had increased markedly (Fig. 1,*B*). The cardiac catheterization indicated high output failure (Table I). The communication between the aorta and coronary sinus was immediately ligated.

Since surgery, compensation has been restored and maintained.



A. *B.*

Fig. 1.—*A*, Posteroanterior view of the heart (Case C. T.) prior to coronary sinus anastomosis. *B*, Posteroanterior view of the heart (Case C. T.) 18 months postoperatively.

TABLE I. CATHETERIZATION DATA

	O_2 CONTENT (VOL. %) AVERAGE OF SAMPLES				ARTERIAL O_2 PRESSURE	PRESSURE (MM. Hg)					CALCULATED ARTERIOVENOUS SHUNTS	
											PREOP.	POSTOP.
CASES	VI	RA	RV	PA		RA	RV	PA	PVC	BA		
1. C. T.	14.6	13.6	12.7	14.0	92.1%	(0)	48/0	50/27 (32)	20	110/90	4.9 L./min.	No shunt
2. D. E.	11.4	13.6	13.8	14.9	91.1%	(6)	70/30	70/40 (48)	12	120/80	2.9 L./min.	Not done
3. C. M.	11.2	12.3	13.3	14.8	97.3%	(6)	60/8	62/24 (34)	(16)	125/80	1.9 L./min.	Not done

Figures in parentheses are mean pressures.

VI—venous inflow; RA—right atrium; RV—right ventricle; PA—pulmonary artery; PVC—pulmonary venous capillary; BA—brachial artery; L./min.—liters per minute.

CASE 2.—E. C., a white man 39 years of age, suffered a myocardial infarction due to atherosclerotic narrowing of the coronary arteries, in 1948. The only residual subjective symptomatology was substernal distress, which became increasingly more severe under ordinary activity, and the patient was admitted to Hahnemann Hospital for the surgical treatment of this disease, in November, 1952.

Physical examination was entirely normal. The blood pressure was 168/100 mm. Hg.

The first stage of the coronary sinus arterialization was performed on Nov. 11, 1952. A section of the subclavian artery was used as a graft between the aorta and the coronary sinus. On Jan. 11, 1953, the patient was readmitted for the second stage of the surgical procedure. At that time his physical examination was essentially unchanged. There was no evidence of congestive heart failure. The graft was discovered to be patent at the time of operation and the orifice between it and the coronary sinus was reduced to 3 mm.

Severe decompensation marked by pulmonary congestion, edema, and hepatomegaly developed in November, 1953. The patient was controlled on a no salt routine until July, 1955, when he was readmitted to the hospital. Cardiac catheterization revealed high output failure.

Following the ligation of the graft between the aorta and coronary sinus, all evidences of decompensation disappeared. The patient has remained well.

CASE 3.—C. M., a white man 69 years of age, was admitted to Hahnemann Hospital, on April 1, 1953, because of substernal distress on effort, which first developed in 1948. The patient was severely incapacitated and could not engage in normal activities. Although he had had severe nocturnal dyspnea with the initial onset of his disease, there was no indication of subsequent congestive heart failure.

Physical examination was normal. The blood pressure was 124/76 mm. Hg. Laboratory examination revealed a hemoglobin of 13.2 Gm. per cent and a red blood cell count of 5 million. The white blood cell count was 6,400, with a normal differential. The blood urea nitrogen was 16 mg. per cent, and the blood sugar was 98 mg. per cent. The serologic studies were negative. The electrocardiographic examination indicated myocardial damage. The x-ray examination of the heart revealed no change in size or contour.

Because the coronary artery insufficiency pain persisted and did not respond to ordinary medical measures, the patient was subjected to coronary sinus arterialization on April 7, 1953. A segment of the left subclavian artery was used as the graft.

At the second stage of the procedure the graft was patent and the coronary sinus opening was reduced to 3 mm.

The patient was readmitted to the hospital because of severe congestive heart failure and recurrent Adams-Stokes syncope.

Cardiac catheterization revealed right output failure (Table I). The graft was ligated immediately, and the patient was discharged with no evidence of congestive failure.

The patient was recatheterized one year after the ligation of the graft, and the results indicated normal dynamics (Table I).

DISCUSSION

The clinical findings and the outcome of events in the 3 patients reported are strikingly similar. Coronary sinus arterialization was advised and carried out in each instance because of advanced incapacitating coronary artery atherosclerosis. The opening of the vascular graft into the coronary sinus was reduced to 3 mm. during the second stage of the procedure. In spite of this precaution the manifestations of decompensation developed within varying periods of time after the operation. In each of the patients the right heart catheterization revealed the evidence of right output failure. Finally, when the anastomosis between the aorta and coronary sinus was eliminated, the clinical picture of failure disappeared. In the only instance in which catheterization was repeated, the cardiac dynamics returned to normal.

The sequence of events in these patients suggests unmistakably that the artificial arterial venous fistula required in this type of operation may cause pathophysiologic effects which can not be tolerated by the left ventricle already rendered abnormal because of decreased coronary blood flow.

From our present experience, the history, physical examination, heart size, and electrocardiographic pattern are not helpful in predicting when this will occur. However, it is logical to contend that the left ventricle is less likely to endure an added volume load when it is unusually enlarged or has been decompensated previously.

The seriousness of high output failure as a complication of coronary sinus arterialization is reflected in the magnitude of the manifestations and the disability encountered in the patients described. This is tempered by the prompt response to ligation.

The incidence of this complication may be reduced by the application of surgical refinements, particularly the side-to-end anastomosis of the aorta and coronary sinus which appears to reduce the size of the fistula and the volume of retrograde blood flow.[6]

SUMMARY

Three patients are reported in whom coronary sinus arterialization, performed for chronic coronary artery insufficiency, was followed by congestive heart failure. Subsequent ligation of the vascular graft from the aorta to the coronary sinus and dilatation of the arteriovenous shunt restored compensation to normal.

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A HIGH SENSITIVITY PICKUP FOR CARDIOVASCULAR SOUNDS

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WITH THE TECHNICAL ASSISTANCE OF W. W. FRANCIS AND J. H. SPROUSE, JR.

CHARLESTON, S. C.

CARDIOLOGISTS have long known that certain heart murmurs of low intensity, those which often are of the greatest importance in early diagnosis of valvular disease, may be audible on careful stethoscopic examination yet not record on the phonocardiogram. It may seem paradoxical that, with the availability of electronic amplifiers of virtually any range and amplification, a comparatively crude instrument such as the acoustical stethoscope should afford the most sensitive means of detection of cardiovascular sounds. This, of course, is due not so much to any special virtues of the stethoscope as to the amazing sensitivity and versatility of the human ear. Conventional phonocardiographic equipment has certain limitations in its responsiveness which the human ear does not have.

Chief limitations in most equipment currently used for reproduction of sounds from the precordium reside in the pickup and, if the sound is to be displayed on paper, the recording oscillograph. As to the latter, restrictions inherent in mechanical or galvanometric recorders are readily obviated by use of the cathode-ray oscilloscope, with its freedom from inertia effects and its unparalleled frequency range. The pickup, on the other hand, appears to us to be the main stumbling block—and the unknown quantity—in an otherwise calibrated recording system. Commonly, microphone-type devices of various sorts have been employed for this purpose, the sounds being transmitted from the body surface through an enclosed air space to the pressure—sensitive element, usually a piezoelectric crystal, condenser, or magnetic transducer.

The pickup described herein is of a basically different type, one not involving air transmission, devised for unusually high sensitivity and wide range in the recording of heart sounds and murmurs. Applied to the precordium it is capable of reproducing cardiovascular sounds of intensities at and below the threshold of stethoscopic audibility.

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This work was supported in part by grants from the National Heart Institute, and the South Carolina Heart Association.

The collaboration of Mr. Sihvonen, Dr. E. J. Martin, Dr. G. M. Rassweiler, and others of the Physics and Instrumentation Department at Detroit was accomplished as a contribution of the General Motors Corporation to medical research.

Received for publication May 2, 1957.

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PRINCIPLES AND DESIGN OF THE PICKUP

The pickup and its associated electronic equipment have been described in detail in a previous publication.[1] It is a relatively simple device, the essential components of which are illustrated in Fig. 1, and utilizes the principle of variation in electrical capacitance between two charged conductors in accordance with change in relative distance between these conductors. One electrode of the capacitor is suspended above the skin while the body surface itself, or a suitable diaphragm, serves as the other capacitor electrode. The associated single tube oscillator is "link coupled" to the pickup through several feet of flexible cable and provides a low-impedance output which may be fed directly into an ordinary cathode-ray oscilloscope. For murmurs of extremely low intensity a preamplifier having a voltage gain on the order of 10 to 50 may be desirable, depending upon the input requirements of the oscilloscope. A frequency response from D.C. to more than 50,000 cycles per second is obtainable from the pickup and oscillator.

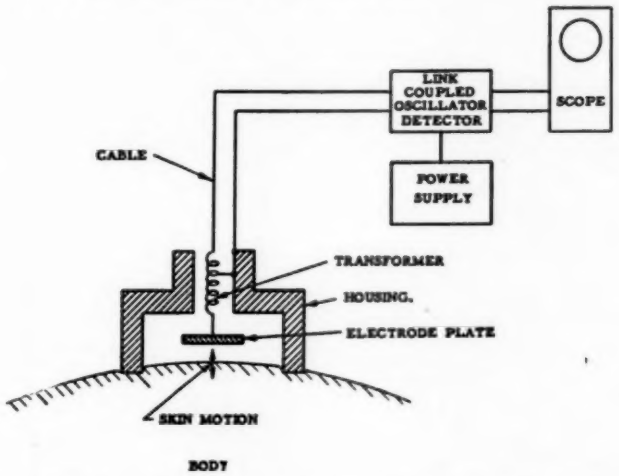


Fig. 1.—Diagrammatic sketch of the capacitance pickup and arrangement of associated equipment. The body surface, in proximity to the electrode plate, serves as the other plate of the capacitor.

Provision is made for use of a diaphragm. This addition does serve to enhance sensitivity of the pickup in the audible range and also makes possible an appreciable degree of frequency discrimination by mechanical filtering (particularly, attenuation of the relatively high amplitude infrasonic vibrations of the chest wall) which may be desirable in some applications. In this event, the thickness and mechanical characteristics of the diaphragm may be utilized to govern the frequency range of the system. A manual adjustment of electrode position, calibrated in steps of five ten-thousandths of an inch, is of particular value when a diaphragm is used in order to obtain very close and reproducible spacings between the two plates of the capacitor for optimum sensitivity. Total weight of the pickup is 2 ounces (50 grams).

APPLICATION

Whether the pickup is used with or without a diaphragm, it is conveniently secured in position on the chest wall simply by its own weight. Some advantages may attend this method of attachment, especially in the recording of low-intensity sounds. Short adhesive straps can be resorted to for fixation on sloping or vertical surfaces, but the long circumferential chest straps often employed in phonocardiography to hold air-conduction microphones in place are not suitable for contact transducers because of the respiratory variation in contact pressure. Omission of the diaphragm often gives rise to a technical difficulty whereby the radio frequency energy present at the pickup electrode is short-circuited by hairs protruding from the skin. This may be avoided by shaving the skin or by coating the electrode with a dielectric material. Or a simple alternative is to interpose a thin sheet of cellophane between the pickup and the precordium since it is not

essential that electrical contact be maintained between them. Actually, it is possible to suspend the entire pickup off the body surface so that there is no contact with the subject whatsoever, although control of spacing with respiratory and other movements becomes difficult. This latter technique offers some unique research applications and has been used for the recording of sounds directly from the open heart, as well as of body movements such as the ballistocardiogram and respiration.

Probably heart sounds, low-frequency vibrations, and even some low-pitched murmurs can be recorded with reasonable fidelity on the ordinary galvanometric recorders. However, the frequency response of these instruments over the audible range is in no way comparable to that of commercially available cathode-ray oscilloscopes which are both calibrated and highly versatile. For the recording of heart murmurs we have found it expedient to use a double-beam cathode-ray oscilloscope and camera, displaying the electrocardiogram on one channel for purposes of timing in the cardiac cycle. A variable electronic filter (resistance-capacitance type*) having an attenuation curve of 18 or 36 decibels per octave has been employed for selection of the desired portions of the frequency spectrum. Arrangement of the entire system is such that the operator can both see and hear the sounds as they are being photographed. Once established, this recording technique is reasonably rapid and convenient, tracings being available from the self-developing camera in about one minute. An absolute time scale for calculation of frequencies may be readily added to the tracings by double exposing on them the wave form of a signal of known frequency.

RESULTS AND DISCUSSION

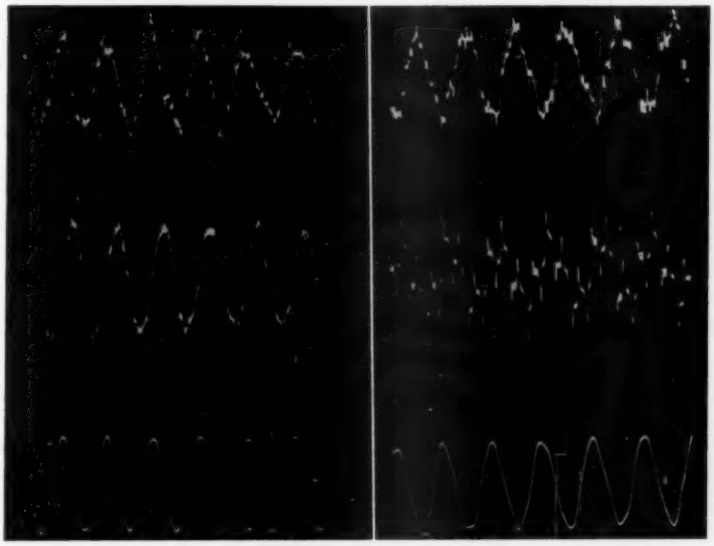
So far as phonocardiographic pickups in general are concerned, we have been impressed with three main problems encountered in extending their usefulness to the sounds of lower intensity which we wish to hear and to record. Ideally for this application a pickup should have a very high effective sensitivity, an adequate amplitude and frequency range, and, insofar as possible, it should discriminate against extraneous room noise in favor of the sounds from the chest wall.

Sensitivity.—From a practical standpoint, sensitivity of a pickup can be measured in terms of the ultimate signal-to-noise ratio. Such a measurement is illustrated in Fig. 2,*A* where the new capacitance pickup is compared with two microphone-type instruments commonly used in phonocardiography. All were applied to recording a very low-intensity tone reproduced in an "artificial precordium"[2] approximating the acoustical impedance of flesh.

Actual voltage output of the link-coupled oscillator (LCO) is plotted against linear displacement of the flesh or diaphragm in Fig. 3. This was obtained by apposing with a micrometer adjustment the two elements of the capacitor (i.e., a grounded electrode toward the pickup electrode). While this curve denotes an alinearity as to amplitude responsiveness it might be pointed out that similar, but less steep, curves can and do obtain at wider electrode spacings by retuning the oscillator for maximum output at the desired spacing. A distance of ¼ inch or more between the electrode and the body surface is practicable for some applications.

The effective sensitivity of any pickup must certainly depend in large part upon the efficiency with which mechanical vibrations are transmitted from the precordium to the vibration-sensitive transducer. In most microphone-type devices this is accomplished through an enclosed acoustical pathway of air. As has been pointed out by previous investigators, "whenever transmission of

*SKL Model 302 manufactured by the Spencer-Kennedy Laboratories, Cambridge, Mass.



A. *B.*

Fig. 2.—Signal-to-noise ratios obtained with three types of pickups recording near the threshold of stethoscopic audibility. (*A*, Intrinsic noise. *B*, Extrinsic noise.) In each case the two traces above were made with conventional condenser (top) and crystal (center) pickups commonly employed in phonocardiography, while the bottom traces were recorded with the capacitance (LCO) pickup. The signal is a sine wave of 350 c.p.s. reproduced in a water-filled transducer.[4] Noise is evident as mottling and distortion of the signal wave form.

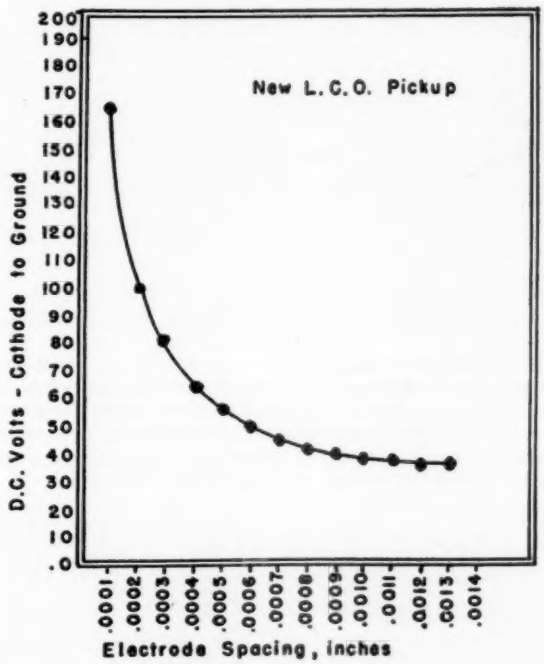


Fig. 3.—Voltage output of the link-coupled oscillator as a function of electrode spacing.

sound from a dense to a rare medium takes place a serious loss of vibrational energy occurs, which is due to reflection of sound waves back into the dense medium."[3] Just how much is lost along the way in sensitivity or fidelity of response has not been determined. Certainly it is true that an underwater sound is detected more readily through water than above the surface. These and other physical considerations involved in the recording of heart sounds have been discussed in previous reports.[4,5] At any rate, our impression has been that a direct contact type of pickup, one which does not depend upon air transmission of sound from the body surface, affords, among other advantages, the greatest effective sensitivity.

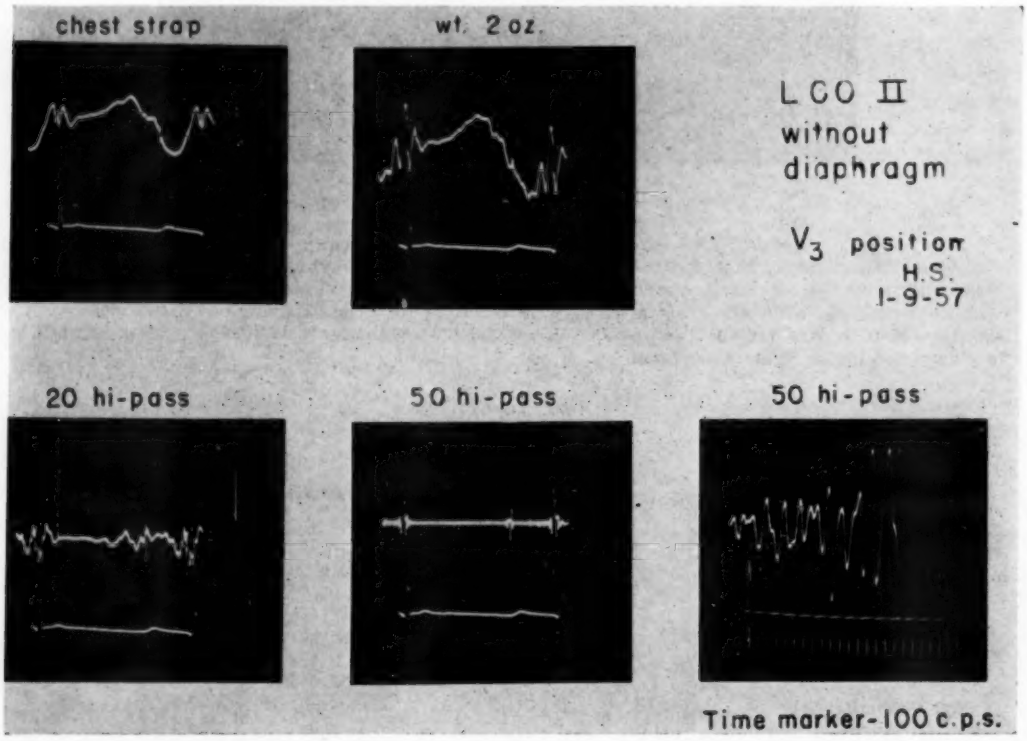


Fig. 4.—Successive recordings of wave forms made with the pickup in the mid-precordial area of a presumably normal subject. In each tracing the electrocardiogram is recorded simultaneously below, and the time axis is from right to left. When only the 2 ounce weight of the pickup is used to hold it in place, the amplitude of the first heart sound complex in relation to the large low-frequency precordial movement is greatly increased over that recorded when a chest strap is used. By further attenuation of low frequencies, electronically, and increasing amplification, a systolic murmur becomes evident in the 50 c.p.s. high-pass tracing. Oscilloscopically the murmur may then be greatly amplified and the time scale expanded to display the wave form of the murmur alone, lower right. A 100 c.p.s. triangular wave is double-exposed below for estimation of the murmur frequencies.

Amplitude and Frequency Ranges.—It has long been known that large low-frequency movements and vibrations resulting from the heart's mechanical activity are present at the chest wall in addition to those of the sounds we hear. Indeed, most of the heart's vibrational energy transmitted to the precordium has been shown to be contained in the infrasonic vibrations variously estimated to be several hundred to several thousand times the amplitude of some of those

in the audible portion of the spectrum.[6,7,8] In general, the higher the frequency of a vibration the lower its amplitude. This necessitates either a pickup which is effectively insensitive in the infrasonic range or one which has an extremely wide amplitude tolerance. Since the capacitance pickup itself has a "D.C. response," low-frequency movements of the chest wall must be filtered out mechanically or electronically, or by both means, in order to reproduce a low intensity murmur. The problem is, as one automotive engineer put it, "like trying to record a faint tapping sound which a customer hears in an engine above all the low-frequency main vibrations of the engine which escape his ear but swamp the recorder." To some extent this can be accomplished mechanically by insertion of a diaphragm of the desired mechanical characteristics, or by making the pickup extremely light so that it "rides" the lower frequencies.

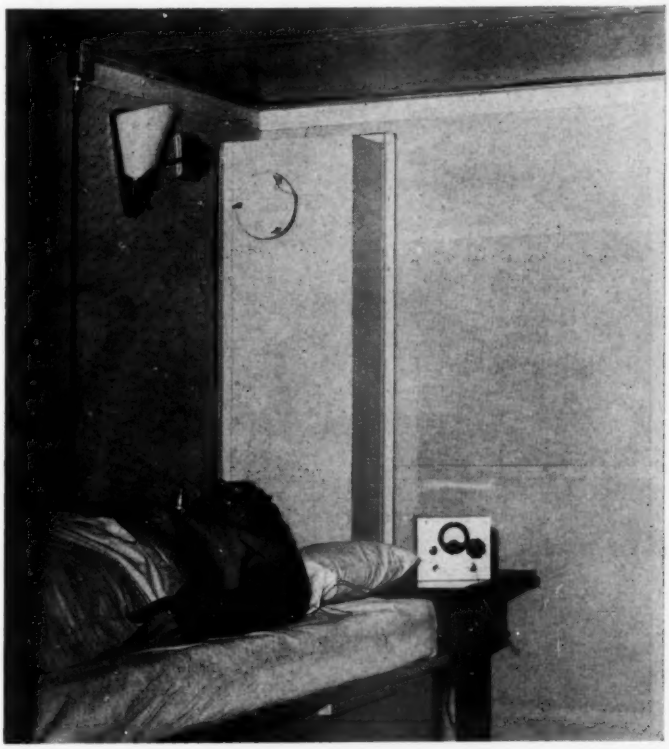


Fig. 5.—Subject in soundproof room as viewed through the open door. The room* is constructed of double walls, floor and ceiling mounted on vibration isolators and has a noise attenuation in excess of 60 decibels over most of the audible frequency spectrum. All recording equipment is kept outside the room except the pickup and its associated oscillator and preamplifier.

***Prefabricated by Industrial Acoustics Co., New York, N. Y.**

Fig. 4 illustrates the effect of mechanical and electronic filtering with progressive attenuation of low frequencies in a subject until a faint systolic murmur is isolated and magnified from the original wave form where it is imperceptible. This was recorded without recourse to a diaphragm, utilizing only the effect of two different pressures against the chest wall, and the low-frequency attenuation of electronic filters. The subject whose murmur is depicted here is a medical student assistant

in the laboratory; his apical systolic murmur had never been detected on numerous clinical examinations and was, in fact, inaudible stethoscopically under ordinary conditions.

The variable and controllable sensitivity of the pickup by means of adjusting its spacing is an additional aid in compensating for the vast differences in amplitude of chest wall excursion encountered among different subjects.

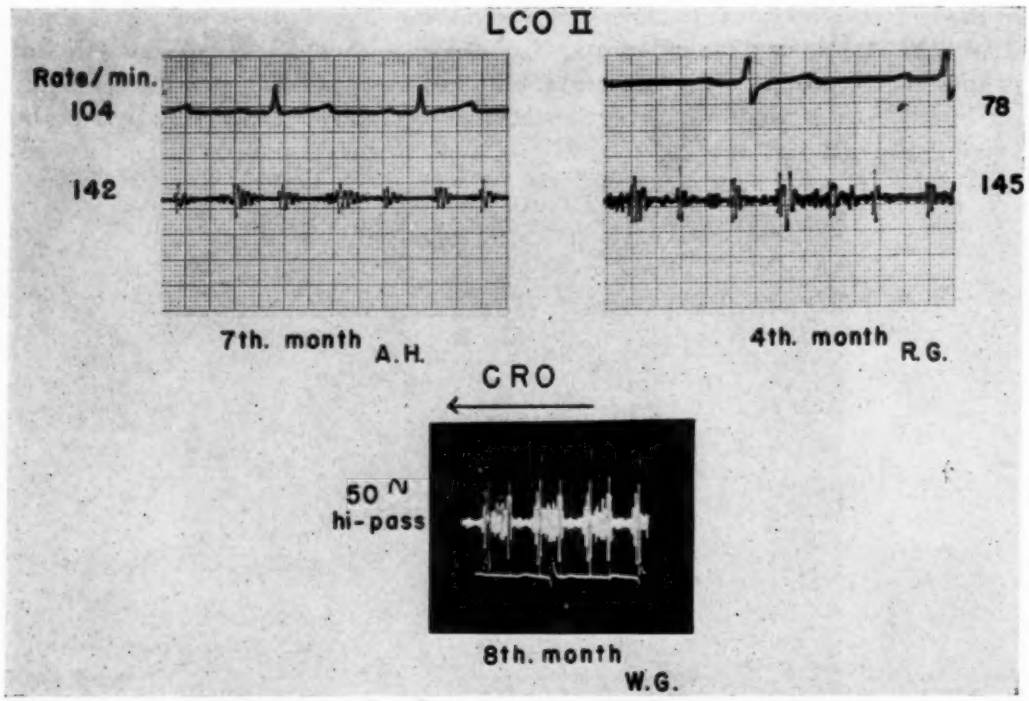


Fig. 6.—Three recordings of fetal heart sounds with simultaneous maternal electrocardiograms. The tracing below was recorded on the cathode-ray oscilloscope and reveals a fetal systolic murmur which was inaudible through the stethoscope.

Inherent frequency response of the pickup is almost unlimited, while that of the oscillator is "flat" to far above and below the audible range. The complete absence of any moving parts or acoustical coupling excludes the usual resonance effects.

Background Noise.—Attempts to increase the sensitivity of a phonocardiogram by increasing the gain of its amplifier usually result in the appearance of excessive noise in the tracings—noise which is extraneous, which does not arise inside the chest. Sounds of much less than moderate intensity may be obscured altogether. The effect of background noise on the physician's ability to detect a faint murmur through the stethoscope has been the subject of a previous study,[2] and its interference in graphic recording techniques is doubtless even greater for the same reason that the trained ear can pick out the tone of a particular instrument from the sound of an entire symphony orchestra. Desirable, therefore, in any recording system of heart sounds is a maximum degree of discrimination against this extrinsic noise in favor of the desired signal.

Without a diaphragm the LCO capacitance pickup is entirely unresponsive to noise. When a diaphragm of the proper characteristics is added the instrument may still be less vulnerable to interference from extraneous sounds, probably by virtue of the fact that its acoustical impedance, adjusted for detection of sounds in a relatively dense medium, can be made higher than that of microphone-type pickups which are designed for air-borne sounds. One might think it possible to gain considerable advantage by such impedance matching alone, the limiting factor of course being that the chest wall itself picks up room noises and transmits them along with the sounds emanating from inside. For this

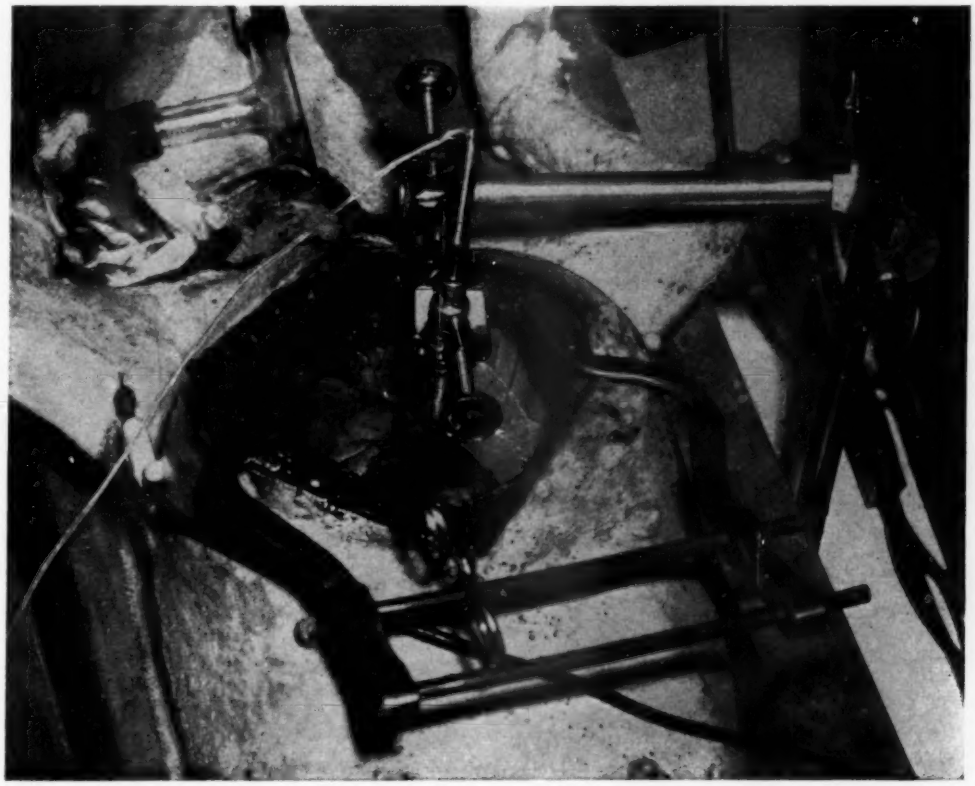


Fig. 7.—Method of recording from open heart. The pickup electrode assembly (housing removed) is rigidly suspended close to, but not touching, the dog's heart. Leads for simultaneous electrocardiogram are attached to the extremities.

reason we have resorted to a rather elaborate soundproof room for our studies of low-intensity murmurs. The room in which these tracings were recorded (Fig. 5) is a 10,000 pound steel and Fiberglas structure in which virtually no extraneous noise is audible.

Nevertheless, when an interfering noise is introduced into the environment, different pickups show remarkably different degrees of discrimination against it. This is evident in Fig. 2,*B* which again portrays comparative recordings of a low-intensity tone by three types of pickups, but in a noise environment comparable to that of the average examining room.

The ultimate signal-to-noise ratio of the entire recording system thus includes extrinsic as well as intrinsic noise, both of which become of major importance as the sensitivity of the system is increased for exploration of the lower-intensity murmurs. In a sufficiently quiet environment it is readily possible with the LCO capacitance pickup to record—or to amplify for listening—sounds which are not ordinarily audible on auscultation. An example is the systolic murmur between the first and second fetal heart sounds shown in the cathode-ray

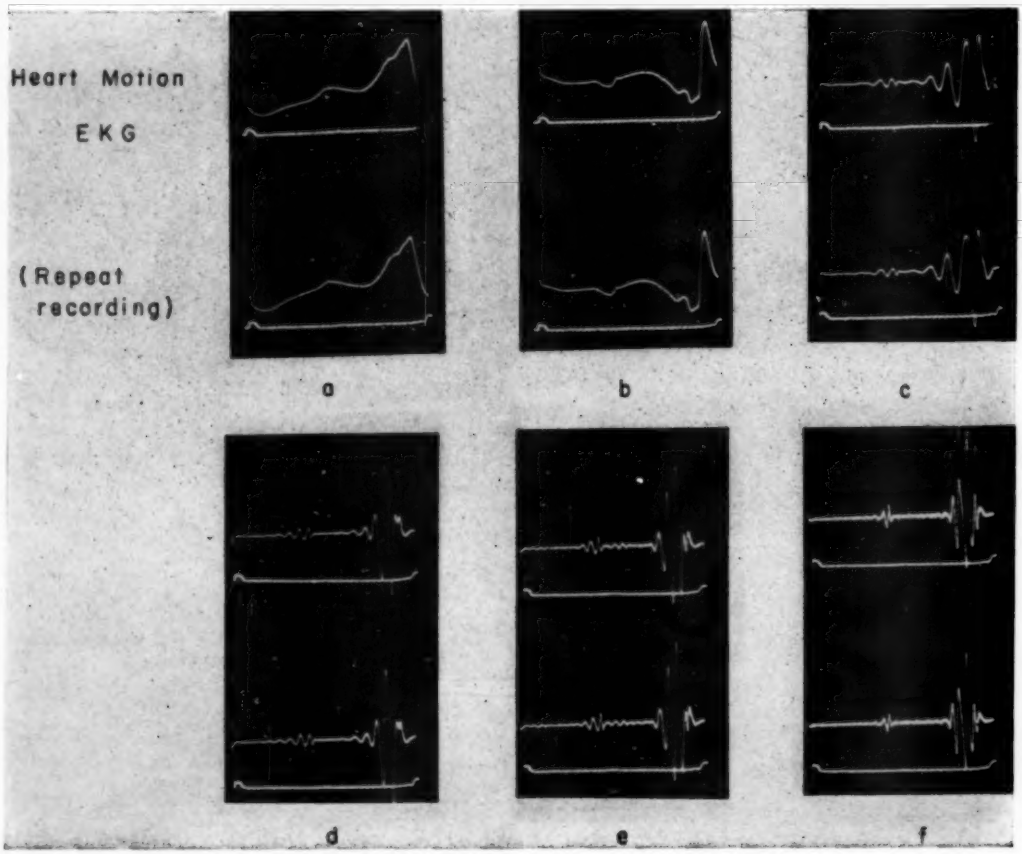


Fig. 8.—Recordings of heart motion with simultaneous electrocardiogram from experiment of Fig. 7. (LCO electrode suspended ½ inch above open dog heart, over A-V groove.) In each instance repeat recordings were made to ascertain their reproducibility. The time axis is from right to left, and one complete cardiac cycle is shown in each tracing. *a*, Gross movement of the heart wall throughout systole and diastole, the limits of which are not demarcated. *b*, Slight attenuation of low frequencies (below approximately 5 to 10 c.p.s.) reveals a suggestion of infrasonic waves appearing in systole, with a shallow wave at the beginning of diastole. *c*, Attenuation of frequencies below 20 c.p.s., and increasing amplification yield infrasonic vibrations associated with first and second heart sounds. These are too low in pitch to be audible. *d*, 30 c.p.s. high-pass recordings. *e*, 40 c.p.s. high-pass recordings. *f*, 50 c.p.s. high-pass recordings. Here only the first (right) and second heart sounds are seen. These are the vibrations which are audible on auscultation.

oscilloscope tracing of Fig. 6. The importance of such a tracing lies not so much in the fact that a presumably normal fetus has a systolic murmur (for it appears that most of them do at this stage of gestation), but that there are more sensitive methods of detecting these sounds than the time-honored stethoscope. For

there is, after all, no real reason to assume that all cardiovascular sounds of significance should be perceptible to the ear with our present methods of auscultation.

Direct Heart Sound Recordings.—A unique property of this pickup whereby motion of a surface may be recorded without touching the surface lends itself to some interesting applications. Such motion is of course not transmitted acoustically but as variation in capacitance between the moving or vibrating body and the pickup electrode which is "proximity sensitive." Hence no acoustical artefacts are introduced, nor is any restriction or damping of movement imposed.

If the electrode is suspended over the open heart as pictured in Fig. 7 direct recordings may be made of the motion (displacement) of the underlying area of myocardial wall. Output of the pickup will include all frequencies: the gross movements of the heart as it beats, the low-frequency vibrations, and the heart sounds. All these are superimposed, as they are at the precordium. But due to their very great differences in amplitude they cannot all be depicted in any single tracing of practicable size. Rather, they must be viewed selectively by appropriate filters and amplifications. Fig. 8 illustrates such a "pyramid" of vibrational energy, recorded from one position over the open dog heart. Wave forms of the heart sounds are exactly reproducible, as shown by repeated tracings, and bear a striking resemblance to those ordinarily recorded from the outer chest wall.

By such direct techniques it may be possible to learn more of the origin of heart sounds and murmurs, their localization, of how much the chest wall adds or detracts, and perhaps more of the significance of the tracings of sounds and vibrations as recorded from the precordium.

SUMMARY

There has long been a need for a practicable electronic method of detecting and recording heart murmurs of very low intensity—sounds at and below the threshold of stethoscopic audibility. To accomplish this necessitates a pickup having high sensitivity and wide range, and extremely low levels of ambient noise both in the recording system and in the environment. We have attempted to devise such a pickup. It is essentially a capacitance transducer which does not rely on air conduction of sound, and which can utilize the body surface itself as one electrode of the capacitor. Clinical and experimental tests of this capacitance pickup indicate that it is uniquely suited to the recording of cardiovascular sounds.

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A SWITCHING CIRCUIT FOR THREE-PLANE STEREOVECTORCARDIOGRAPHY

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VECTORCARDIOGRAMS recorded in two planes which intersect at a small angle may be fused in a stereopticon to give an observer the impression that he is viewing a three-dimensional figure. In general, three methods have been employed to record such paired tracings for stereoscopic viewing:

1. *The Use of Special Electrode Positions.*—Stereovectorcardiograms recorded by this method are usually limited to a single plane. Thus, two slightly tilted frontal plane tracings have been obtained by placing electrodes on the anterior and posterior aspects of the right shoulder[1] or of both shoulders.[2] The author earlier recorded transverse plane stereovectorcardiograms by modifying the technique of Donzelot and associates.[3] The sagittal component on each oscilloscope consisted of Lead V_2. The transverse component on the left scope was formed by Lead V_{5-6}, while the transverse component on the right scope consisted of a lead between the same precordial electrode and a junction of electrodes located on the right and left arms.

2. *The Use of Special Circuits.*—Suitable resistances were introduced at appropriate points between the back electrode and the two arm electrodes of the tetrahedron in order to obtain two vectorcardiograms, each rotated in an opposite direction about 3 degrees out of the frontal plane.[4] This same type of resistor circuit was later applied to all four triangular surfaces of the equilateral tetrahedron to obtain stereovectorcardiograms in the frontal, left, right, and superior planes.[5]

3. *The Use of an Electronic Resolver.*—Schmitt and his associates[6,7] have developed the "stereovectorelectrocardioscope" which allows potential differences recorded with any system of orthogonal leads to be rotated spatially so that they can be viewed stereoscopically from any desired azimuth and elevation. Such a device represents the ultimate in vectorcardiographic equipment, but its usefulness is somewhat limited by its complexity and cost.

The purpose of the present communication is to describe a simple switching circuit which may be interposed between three amplifiers and two cathode-ray oscilloscopes to obtain planar vectorcardiograms tilted at an angle of approximately 6 degrees with respect to each other in the frontal, sagittal, and transverse planes. The wiring diagram of this circuit and its connections to the plates of the oscilloscopes are depicted in Fig. 1. The orthogonal leads are attached to the paired X, Y, and Z terminals. Tracings are obtained with the rotary switch successively located at the F (frontal), S (sagittal), and T (transverse) positions. With reference frames formed by three leads having unequal magnitudes,[5,8,9] it is necessary to vary the outputs of the three amplifiers in accordance with the standardizing factors advocated for the frame in question. In the case of reference frames formed by three leads having presumably equal magnitudes,[10,11] the amplifiers are adjusted to have equal sensitivity. The shunt resistance, R,

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Received for publication June 11, 1957.

is placed in the circuit to reduce the voltage across the C termainals before it is fed to the plates controlling the vertical deflections of the two oscilloscopic beams. This voltage reduction is necessary because of the diminution in the horizontal deflections of the oscilloscopic beams resulting from the resistor networks connected to the −A and −B terminals. The value of R is dependent upon the input impedances of the oscilloscopes. If these impedances are unknown, the value of R must be determined experimentally. This may be done most conveniently by applying a standardization signal simultaneously to each of the three amplifiers, the outputs of which have been previously adjusted to be equal.

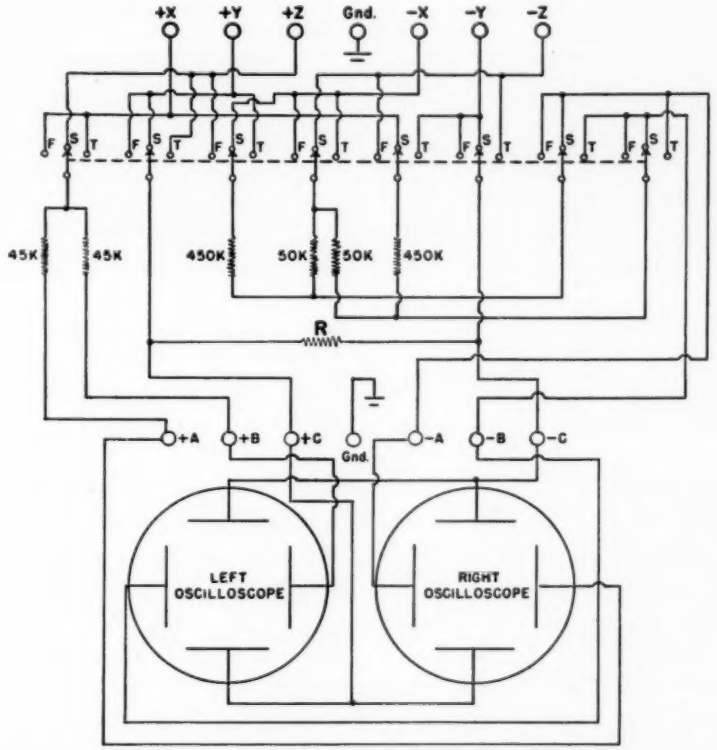

Fig. 1.—Wiring diagram described in the text. The switch is a 4-section, 8-pole, 5-position rotary unit (Centralab No. 1431). Only 3 positions are utilized for the frontal, sagittal and transverse planes. The angulation between the two planes is approximately 6 degrees. Greater or lesser angulation can be obtained by selection of different resistances. See text for explanation of the shunt resistance, R.

The resistance R is then varied until each of the oscilloscopes shows identical deflections of 45 degrees when the rotary switch is located successively at the frontal, sagittal, and transverse positions.*

Fig. 2 illustrates the frontal, sagittal, and transverse views of a stereovectorcardiogram recorded from a patient with right ventricular hypertrophy due to pulmonic stenosis. The reference frame used for these tracings has been described recently.[11]

*With the Technicon Vectorscope used by the author the value of R is one megohm.

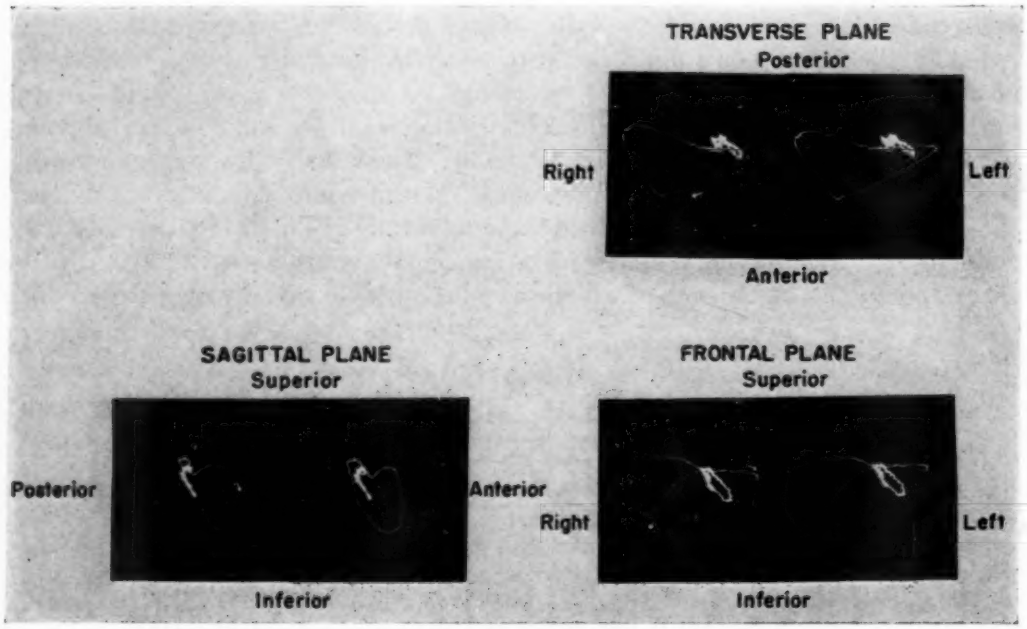

Fig. 2.—Frontal, sagittal, and transverse views of a stereovectorcardiogram recorded from an individual with right ventricular hypertrophy due to pulmonic stenosis. The cathode-ray beam was interrupted at a frequency of 2,000 per second.

SUMMARY

A simple circuit has been described which may be interposed between three amplifiers and two cathode-ray oscilloscopes to record stereovectorcardiograms in all three mutually perpendicular planes with any reference frame of orthogonal leads. This represents a considerable advantage over single plane stereoscopic systems in visualizing the configuration of a spatial loop.

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Clinical Reports

CONGENITAL ATRESIA OF THE ABDOMINAL AORTA

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WHILE congenital anomalies of the thoracic aorta are not uncommon, anomalies of the abdominal aorta are exceedingly rare. We record here a case of congenital atresia of the abdominal aorta presenting as a low aortic coarctation.

CASE REPORT

A 22-year-old African male upon a routine medical examination was found to have hypertension and was referred for further investigation. There were no symptoms and he was able to complete a full day of manual labor without discomfort. There was no impotence and no history of intermittent claudication.

Examination.—Examination revealed a well-nourished man of small stature. His measurements were: height—63¼ inches; ground to pubis—31½ inches; span—65½ inches. His blood pressures were: right arm—180/100 mm. Hg; left arm—190/110 mm. Hg. No blood pressures were recordable in the lower limbs. Both radial pulses were well and equally palpable, not collapsing and not sclerotic. There were no obvious pulsations in the neck or supraclavicular fossae. There was *no* evidence of a collateral circulation around the scapulae. Distinctly visible and palpable arterial pulsations were present in the lumbar, lower intercostal and subcostal regions. The inferior and superior epigastric vessels were particularly prominent, tortuous, and sclerotic. The optic fundi were normal. The heart was not clinically enlarged and the cardiac impulse did not suggest any degree of left ventricular hypertrophy. No thrills were present. The first heart sound was not accentuated and was followed by a Grade 1 systolic murmur maximal in the fourth intercostal space to the left of the sternum. The second heart sound was closed and accentuated in the aortic area. There were no murmurs in the interscapular region. A Grade 2 systolic murmur was heard over the upper lumbar spinous processes and over the epigastrium in the midline. The remainder of the physical examination was essentially negative.

Laboratory Investigations.—Urinalysis—microscopic and chemical examination, normal; concentration test, S.G.—1,025; dilution test, S.G.—1,003. Blood urea was 32 mg. per 100 ml.; blood creatinine, 1.1 mg. per 100 ml. Full blood count was normal. The Wassermann reaction was negative. The electrocardiogram revealed left ventricular hypertrophy without strain.

Comment.—The preoperative diagnosis, both clinical and radiologic (*vide infra*), was obstruction of the lower thoracic or upper abdominal aorta, probably a coarctation.

From the Baragwanath Hospital and University of the Witwatersrand, Johannesburg.
Received for publication Feb. 14, 1957.

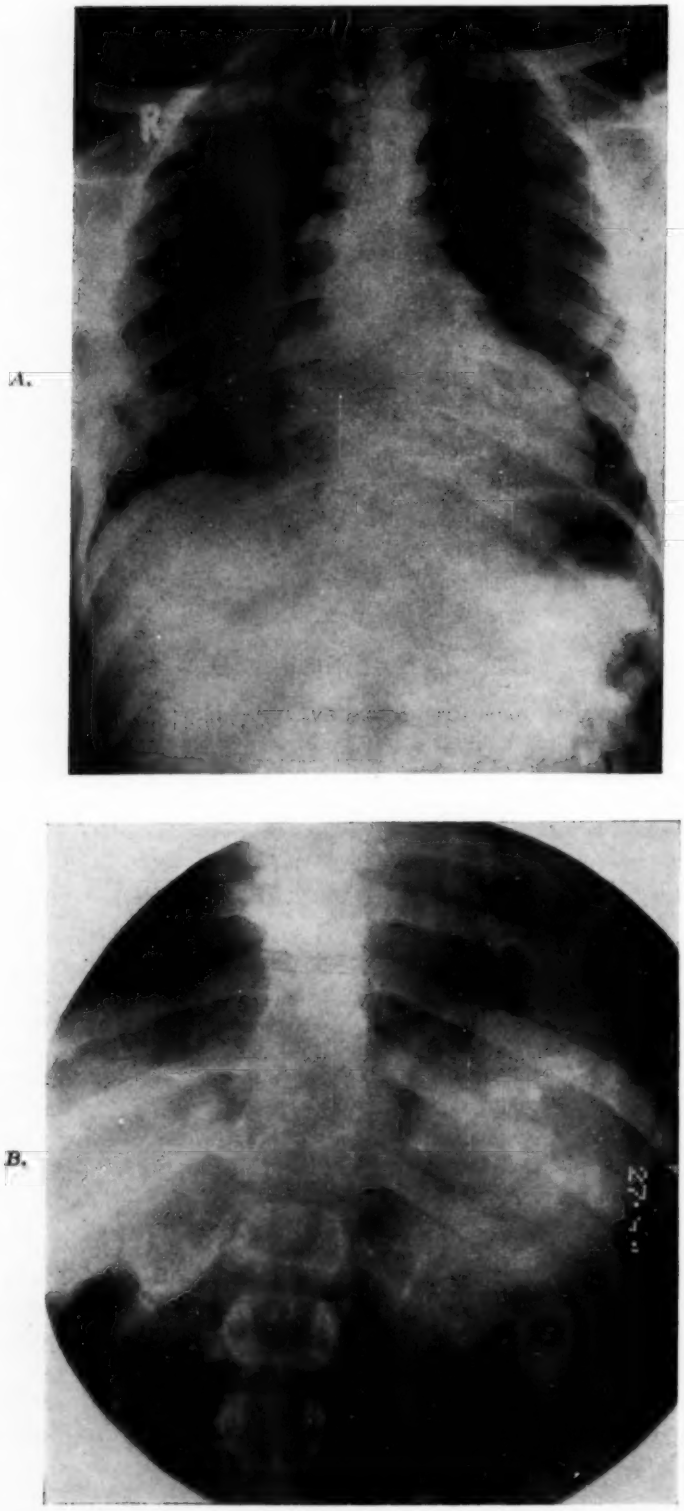

Fig. 1.—*A*, Posteroanterior radiograph of the chest showing marked localized rib notching. *B*, A coned view of the lower ribs showing marked localized rib notching. Note the calcification in the collateral vessels.

Radiologic Examination.—A posteroanterior radiograph of the chest (Fig. 1*A*) showed normal cardiac contours. Gross notching of the eighth rib on the left and the eighth and ninth ribs on the right was noted (Figs. 1*A* and 1*B*). The notches were both deep and wide, and several notches were present on each rib. Minimal notching of the seventh and ninth ribs on the left and the seventh and tenth ribs on the right was present. Calcification in the collateral vessels was noted in the coned view (Fig. 1*B*).

Fluoroscopy revealed minimal left ventricular hypertrophy.

A composite diagram of the preoperative and operative aortograms is shown in Fig. 2. The preoperative aortogram, performed via the left carotid artery, demonstrated a normal aortic contour to the level of the diaphragm where it tapered abruptly. This aortogram also revealed markedly dilated internal mammary, superior, and inferior epigastric arteries. (*E*, *F*, and *G*, in Fig. 2). The incidental pyelogram was normal although no renal arteries could be demonstrated, suggesting that the renal blood supply was derived from capsular arteries A retrograde aortogram via the "femoral" arteries was considered unjustified, as trauma to a collateral vessel or "femoral" artery might have jeopardized an already impoverished blood supply. The anteroposterior view of the abdominal aortogram performed during the operation was unsuccessful.

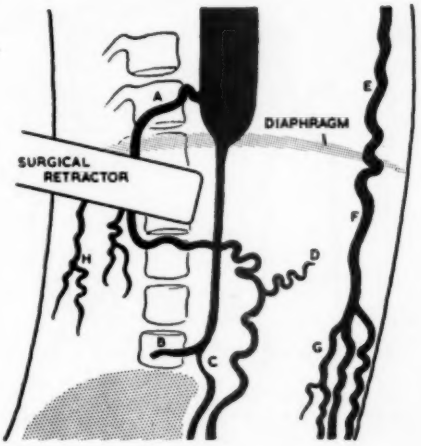

Fig. 2.—A semidiagrammatic composite figure of the preoperative and operative aortograms showing the atresia of the abdominal aorta with collateral vessels *A*, *B*, *C*, *D*, and *H* (see text); internal mammary artery *E*; superior epigastric artery *F*; and inferior epigastric artery *G*.

The lateral view of the abdominal aortogram is illustrated as incorporated with the preoperative aortogram in Fig. 2. The abdominal aorta is seen to be atretic throughout its course in the abdomen, terminating in a vessel (*B* in Fig. 2) probably gluteal, proceeding posteriorly, and in a small vessel (*C*) proceeding to the femoral region. *A* is a large collateral vessel arising from the aorta above the diaphragm and coursing through the lumbar region and abdomen, where it supplies a large branch (*D*) to the viscera, and then enters the anterior region of the thigh. Other collateral vessels in the lumbar region (*H*) were also noted.

Operation.—Thoracotomy revealed large collateral vessels in the chest wall which were ligated. The thoracic aorta was normal down to the diaphragm where it suddenly tapered to a vessel approximately ¼ inch in diameter. A pronounced thrill was felt at this level. The atretic aorta was explored for a further 11½ cm. and was seen to taper downwards progressively in a "rat-tail" fashion, ending in a small unidentified collateral artery. Two large vessels were noted arising from the anterior part of the aorta approximately 2 inches above the diaphragm and then proceeding parallel with the aorta to pierce the diaphragm. Insertion of the needle for an operative aortogram was difficult, as the aorta above and in the region of the atretic portion was heavily calcified. Correction of the atresia with a graft was not anatomically possible. Furthermore, any suturing of the heavily calcified vessels would have been extremely hazardous.

DISCUSSION

Atresia of the aorta other than at the arch is rare. To date, 4 cases in the lower thorax have been recorded: Schlesinger,[8] 1835; Costa,[1] 1930; Schleckat,[7] 1933; Hasler,[2] 1911; and 4 cases in the abdomen: Power,[5] 1861; Maycock,[4] 1937; Holten,[3] 1950; Ritchie and Douglas,[6] 1956.

Clinically, this case appears as a low aortic coarctation, viz., hypertension in the upper extremities, hypotension in the lower extremities, diminished and delayed femoral pulsation, no collateral circulation around the scapulae but evidence of a marked collateral circulation in the abdominal and lumbar regions.

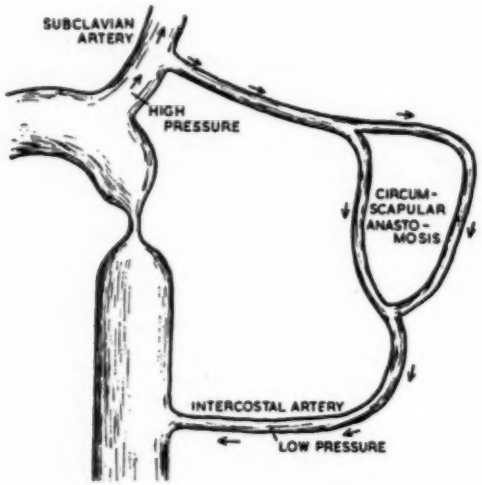

Fig. 3.—Diagrammatic representation of the dynamics of the collateral circulation in a coarctation of the upper thoracic aorta.

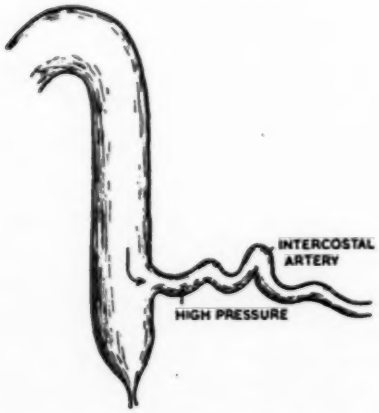

Fig. 4.—Diagrammatic representation of the dynamics of the collateral circulation in an obstruction of the lower thoracic or abdominal aorta.

A delayed systolic murmur (timed with cardiac systole) over the epigastrium and lumbar spines may be of significance. A collateral circulation per se may give rise to systolic murmurs, but a loud delayed systolic murmur in the midline may have particular value in localizing the obstruction.

The outstanding feature of this case is the depth, width, and multiplicity of the notching confined to 1 or 2 ribs. This is due to the fact that the dynamics of the collateral circulation differs from that found in the classical upper thoracic coarctation. In an upper thoracic coarctation, the collateral circulation proceeds from the aorta via the left subclavian artery through the circumscapular anastomosis and thence through the intercostal arteries back to the aorta (Fig. 3). The pressure in the intercostal arteries is relatively low, due partly to the pressure being "spent" en route through the anastomosis, and due partly to some of the pressure being diverted through the subclavian artery (Fig. 3). In the case of a low obstruction (from whatever cause) the pressure in the intercostal arteries is very high due to direct transmission of the aortic pressure to the intercostal artery (ies), further accentuated by the absence of a diversional route such as a subclavian artery (Fig. 4). This relatively high pressure in the intercostal arteries will result in gross localized rib notching, and wherever this is found a low aortic obstruction should be suspected. This high pressure also accounts for the marked sclerosis of the collateral vessels.

SUMMARY

1. A case of congenital atresia of the abdominal aorta is presented.
2. The significance of gross localized rib notching in relation to the altered hemodynamics of a low aortic obstruction is discussed.

We wish to thank the Superintendent of Baragwanath Hospital for permission to publish this case. Our thanks are due also to Mr. G. R. Crawshaw for the operation report, and to Dr. M. Denny and the Radiology Department of Baragwanath Hospital for their assistance with the radiologic reports. We are indebted to Mr. A. M. Shevitz for the photographic reproductions.

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CORRECTED TRANSPOSITION OF GREAT VESSELS

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INTRODUCTION

"Corrected transposition of great vessels" is a rare congenital cardiac anomaly first described by Rokitansky[1] in 1875. It is manifested by complete transposition of both the ventricles and the great vessels. There is a normal right atrium from which blood flows through a bicuspid (mitral) valve into a ventricle with the anatomic features of the left ventricle, and then into a normal pulmonary artery. Blood drains from the pulmonary veins into a normal left atrium, through a tricuspid valve into a chamber with the characteristics of the right ventricle, and then into the aorta. The great vessels are completely transposed from the standpoint of their relative position, as are the ventricles. Most of the reported cases have associated anomalies of the cardiovascular system, the most common being interventricular septal defects.

The abnormal mechanisms of this anomaly are comprehensively discussed or reviewed by Rokitansky,[1] Spitzer,[2] Walmsley,[3] Abbott,[4] Harris and Farber,[5] Liebow and McFarland,[6] Gould,[7] and Lev.[8,9] Spitzer's conception[2,3,5,6] of the role of "torsion" and "detorsion" in the production of cardiac anomalies has been accepted by some authors[5,6] as the underlying basis for "corrected transposition," but others[3] believe that a situs inversus of the ventricular loop is the basic maldevelopment, postulating at the same time an independence of the ventricular loop from the other parts of the cardiac tube during the early stages of development. Abbott[4] describes 4 cases of "corrected transposition," all accompanied by associated anomalies.

The following case is that of a 36-year-old man with "corrected transposition."

CASE REPORT

The patient (W.K.) was a 36-year-old white male bookkeeper who was in excellent health until 1944, when he experienced sudden collapse 3 days after an uneventful tonsillectomy. He was hospitalized, and a diagnosis was made of complete heart block secondary to myocarditis. Angiograms done at that time revealed an enlarged left ventricle and possible hypoplastic aorta. Following discharge from the service, exertional dyspnea developed and became progressively worse.

Received for publication March 6, 1957.

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In October 1949, the patient was admitted to another hospital and treated with the usual measures for congestive heart failure. The final diagnosis at that time was inactive rheumatic heart disease with complete heart block.

The patient was admitted to the Syracuse Veterans Administration Hospital for the first time on July 6, 1953, with symptoms of increasing dyspnea, nausea, and vomiting. Physical examination revealed a chronically ill white man who was in slight respiratory distress with cyanosis of the lips and nail beds. The pulse was 48, blood pressure, 112/80 mm. Hg, and rectal temperature, 98.6° F. There was slight scleral icterus. The neck veins were distended in the upright position and pulsations were visible. The point of maximal impulse and left border of cardiac dullness were in the sixth intercostal space at the anterior axillary line. The heart sounds were of poor quality. P_2 was greater than A_2. There was a Grade 2 apical systolic murmur. The rhythm was regular with a ventricular rate of 48. The liver was enlarged 3½ fingerbreadths below the right costal margin, with a smooth, tender and nonpulsatile edge. There was a palpable fluid wave in the abdomen, and 1 plus pretibial pitting edema.

Pertinent laboratory findings included a 1 plus albuminuria with 3 hyaline casts per high power field. The A/G ratio was 3.3/2.1 and icterus index was 28. The hematocrit was 46 with a 10,300 white blood cell count (76 per cent polymorphonuclear leukocytes, 20 per cent lymphocytes, 4 per cent monocytes). The electrocardiogram revealed right ventricular hypertrophy with complete heart block. Fluoroscopy revealed cardiomegaly (both right and left sides) with a hypoplastic aorta. Cardiac catheterization indicated that the right auricular samples had oxygen saturations similar to those obtained from the inferior and superior venae cavae. High ventricular and diastolic pressures and high mean auricular pressure were compatible with congestive heart failure.

A regimen directed toward control of congestive failure included digitalis, mercurial diuretics, and sodium restriction, as well as a high-protein diet. The patient was readmitted on Sept. 6, 1955, with symptoms of increasing congestive heart failure. Physical findings were essentially unchanged except for evidence of right pleural effusion, increased ascites, and peripheral edema. The electrocardiogram now revealed auricular fibrillation with complete heart block. The usual measures directed at controlling congestive failure were without effect and the patient expired on Oct. 30, 1955. The final diagnosis was "heart disease, unknown type," with congestive failure.

Post-Mortem Examination.—The main findings of interest at post-mortem examination (S.V.A.H.A55-106) were in the heart, in which there was a complete transposition of the arterial trunks from the standpoint of their relative position, accompanied by a transposition of the ventricles with re-establishment of the correct hydrodynamics. The heart was markedly enlarged, weighed 900 grams, and measured 17 cm. in transverse diameter and 14.5 cm. from base to apex. In situ, it was rotated to the left approximately 45 degrees, and there was complete positional transposition of the aorta and pulmonary artery. There was a prominent bulge of the outflow tract of the ventricular chamber, located to the left, which appeared to be continuous with the anteroposed aorta. The venae cavae and pulmonary veins entered the right and left atrial chambers, respectively, in a normal manner.

The dextroposed ("right") ventricle measured 1.0 cm. in average thickness, and was separated from a somewhat dilated, but otherwise normal, right atrium by a bicuspid atrioventricular valve which exactly resembled, except for "mirror-image" reversal, the usual mitral valve (Fig. 1). The relationships of the inflow and outflow tracts of this ventricle, the latter of which was continuous with the posteroposed pulmonary artery (Fig. 2), and the anatomic arrangement and morphology of the columnae carneae and papillary muscles exactly resembled, except for "mirror-image" reversal, those of a dilated enlarged left ventricle.

The levoposed ("left") ventricle measured 1.1 cm. in average thickness, and was separated from a somewhat dilated, but otherwise normal, left atrium by a tricuspid atrioventricular valve which exactly resembled, except for "mirror-image" reversal, the usual tricuspid valve (Fig. 3). The relationships of the inflow and outflow tracts of this ventricle, the latter of which formed a displaced "pulmonary conus" (the previously described bulge), which was continuous with the anteroposed aorta (Fig. 4), and the anatomic arrangement of the columnae carneae, which were of markedly increased prominence, and the papillary muscles, exactly resembled, except for "mirror-image" reversal, those of a dilated hypertrophied right ventricle.

Fig. 1. *Fig. 2.*

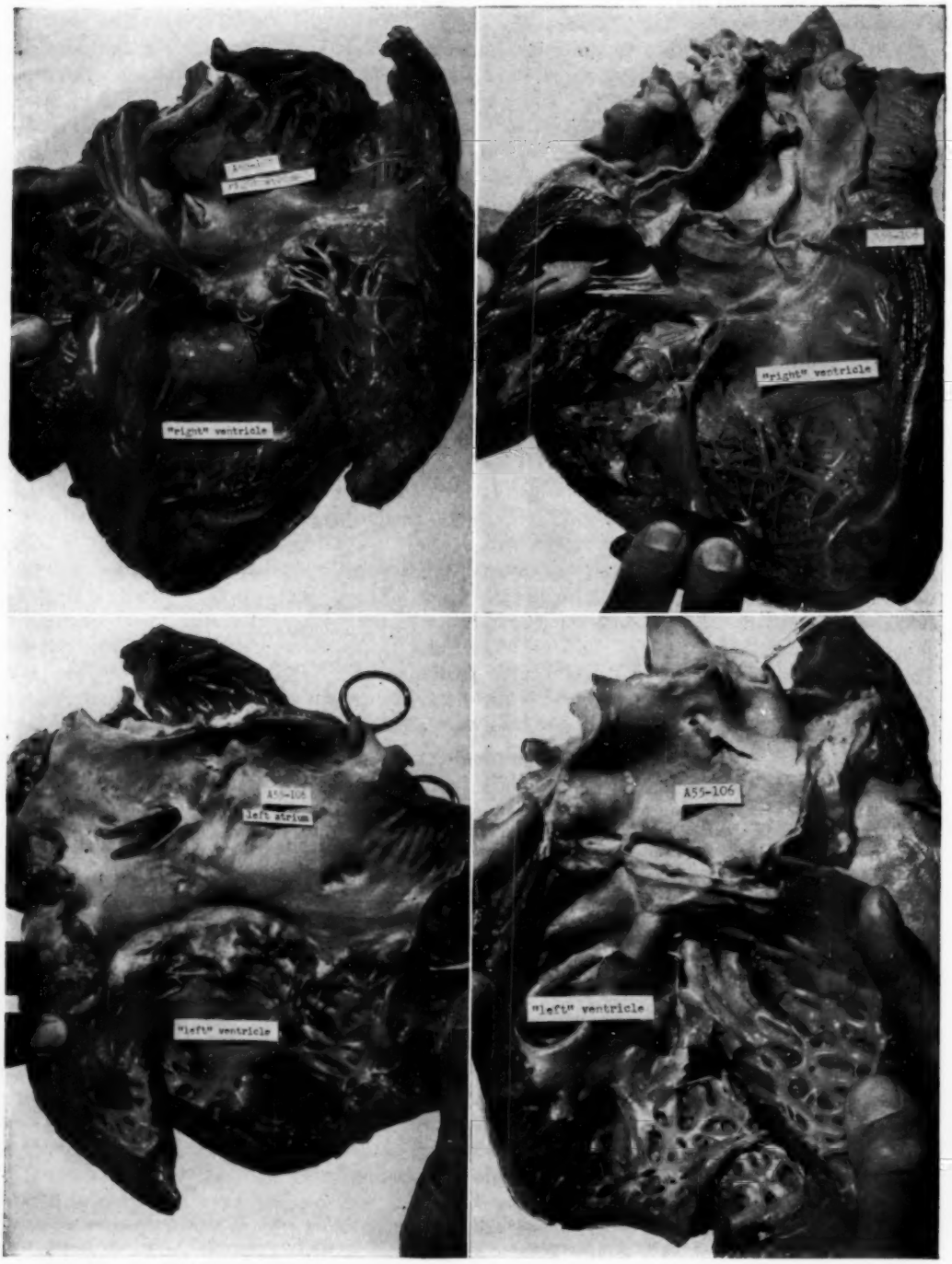

Fig. 3. *Fig. 4.*

Fig. 1.—Right-sided chambers and atrioventricular valve. Fig. 2.—Dextroposed ventricle and pulmonic valve. Fig. 3.—Left-sided chambers and atrioventricular valve. Fig. 4.—Levoposed ventricle and aortic valve.

Figs. 1-4.—From the Medical Illustration Laboratory, Syracuse V. A. Hospital, Syracuse, N. Y.

The right and left atrioventricular valves and the pulmonic valve were of slightly increased circumference, but not otherwise remarkable. The foramen ovale was widely patent anatomically, but not functionally.

The coronary arteries maintained the usual distribution, but, because of the transposition of the aorta and pulmonary artery, had a somewhat altered origin (Fig. 5). There was rotation of the orifices and the corresponding aortic valve cusps through approximately 180 degrees, causing the following anatomic variations: the left coronary artery emanated from a right anterolateral sinus of Valsalva, and the right artery from a left posterior sinus of Valsalva of the anteroposed aorta. The proper posterior cusp was situated in an anterior-to-left anterolateral position.

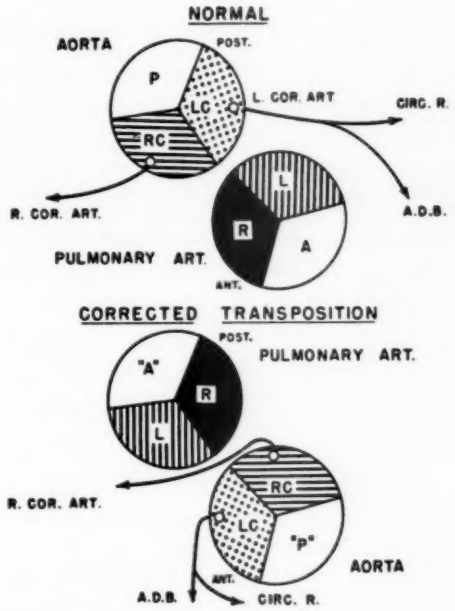

Fig. 5.—Comparative diagram of "normal" pulmonic-aortic trunk and valve arrangement, and that in this case of "corrected transposition." Cusps of aortic valve: *LC*—left coronary, *RC*—right coronary, *P*—posterior. Cusps of the pulmonic valve: *L*—left, *R*—right, *A*—anterior. "*P*"—formerly posterior cusp of aortic valve. "*A*"—formerly anterior cusp of pulmonic valve. (From the Medical Illustration Laboratory, Syracuse V. A. Hospital, Syracuse, N. Y. Negative 671A.)

The pulmonic valve cusps were similarly rotated, but the opposition of the proper anterior commissure (now posterior) of the aortic valve and proper posterior commissure (now anterior) of the pulmonic valve was maintained.

There was moderate coronary atherosclerosis, and a very recent (terminal) occlusive thrombus of the left circumflex ramus, without relevant myocardial changes.

DISCUSSION

This patient with corrected transposition remained entirely asymptomatic until early adult life, at which time his course was marked by heart block and progressive congestive heart failure. The absence of other significant cardiac anomalies, and survival for 36 years makes this case clinically and anatomically very similar to the one described by Walmsley[3] in 1931.

In this case, there was marked cardiomegaly which, it is hypothesized, was due to progressive hypertrophy and dilatation of a misplaced right (levoposed)

ventricle that was unable to tolerate the persistent pressure load of the systemic circulation, leading eventually to intractable cardiac failure. It is suggested that the persistent heart block in this patient was due to conduction system abnormalities engendered by the anatomic ventricular transposition, a hypothesis similar to that expressed by Walmsley,[3] in regard to his case. An attempt to confirm or deny one or another of the theories of pathogenesis of this particular anomaly is not made in the present paper.

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CONGENITAL VALVULAR STENOSIS OF PULMONARY AND AORTIC VALVES WITH ATRIAL SEPTAL DEFECT

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COMBINED involvement of both the pulmonary and aortic valves in the absence of fibroelastosis must be a rare lesion, for we have been unable to find a similar case in the literature. Trivalvular stenosis in a case of endocardial fibroelastosis has been described.[1] The present case is presented because we believe that the hemodynamic data should permit adequate suspicion of the existence of obstruction to left ventricular outflow in the presence of pulmonic stenosis with atrial septal defects. The combination of a systolic pressure gradient across the pulmonary valve of more than 40 mm. Hg, plus a left-to-right shunt at the auricular level, should arouse suspicion of the added presence of obstruction to aortic outflow. The diagnosis can be confirmed then by angiocardiography or left heart catheterization. Combined pulmonic and aortic valvulotomy, plus repair of the septal defect, would allow complete correction of the congenital defect.

CASE REPORT

The patient was a 4-month-old male infant who was the third child of healthy parents. The other children, aged 7½ and 5 years, were both well. The baby was born 1 month prematurely and weighed 6 pounds, 5 ounces. The labor was uneventful and the baby was somewhat cyanosed at birth, but this cleared following the administration of oxygen. Growth and development had been normal.

The infant had been noted to have "choking spells" since birth. These first occurred when he wakened in the morning and would also occur at the time of feeding. The mother described these as "gagging" episodes, during which he would turn blue around the mouth "until he got his breath." He developed a cold about 1 month prior to admission and since then the choking attacks had been more severe. He was hospitalized briefly in another city, and because of the cardiac enlargement and murmurs, a tentative diagnosis of interventricular septal defect was made. He was referred to the University Hospital for further study.

Physical examination revealed an active child, weighing 12.3 pounds, and measuring 25 inches in height. Rectal temperature was 99.4° F., pulse 140 per minute, blood pressure 74/50 mm. Hg, and respirations 44 per minute. He was slightly underweight for his height and age. There was no cyanosis or clubbing. Jugular venous pressure was normal and there was no excessive jugular pulsation. There was slight prominence of the left precordium, most marked at the lower end of the sternum. There was a palpable first heart sound at the apex. The over-all heart size was increased, with the apex at the anterior axillary line in the fifth intercostal space. A Grade 3 to 4 (out of 6) holosystolic murmur was audible at all valve areas, but appeared maximal at the lower sternal edge. The first heart sound was heard at all valve areas, but the second heart sound was very poorly heard, especially at the base. Both femoral arteries were palpable. The remainder of the examination was within normal limits.

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Received for publication March 11, 1957.

Our clinical impression was that of acyanotic congenital heart disease, most likely an interauricular septal defect with associated pulmonic stenosis. This was based on the very loud holosystolic murmur associated with diminished or absent second heart sound at the base.[2] Pertinent investigation included the following:

1. Hemoglobin 11.5 Gm. (73 per cent); W.B.C. 9,200; E.S.R. (micro) 3.0 mm. per hour; urinalysis, S.G. 1,025, negative for albumin, sugar, and acetone; occasional W.B.C.

2. X-rays. The diaphragms were normal with clear angles. The heart was grossly enlarged. There was no evidence of any enlargement of the left atrium or right ventricle. There was moderate enlargement of the left ventricle. The lung fields were normal (Fig. 1,*A* and *B*).

3. The electrocardiogram (Fig. 2) was suggestive of incomplete right bundle branch block. There was definite evidence of right ventricular hypertrophy and evidence suggestive of left ventricular hypertrophy. Ziegler's criteria for normal voltages were used.[3]

4. Cardiac catheterization results are shown in Table I.

TABLE I

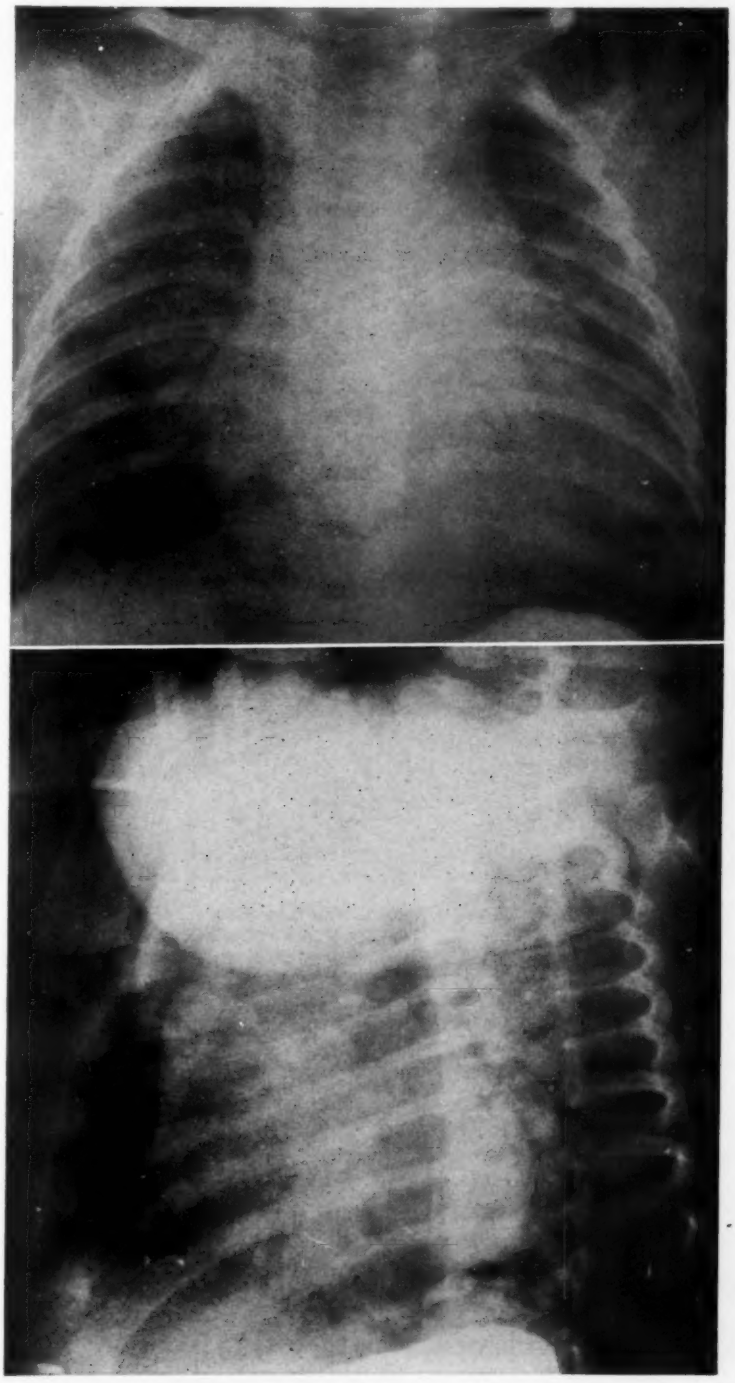
	CO_2 (VPC)	O_2 (VPC)	PER CENT SATURATION	HEMATOCRIT	PRESSURE (MM. HG)
PA (right)	40.39	11.34	83	29	20/10 mean 10
RV (mid)	42.84	11.03	81	30	80/ 0
RV (low)	42.84	11.26	82.5	30	
RA (low)	42.44	11.39	83.5	29.5	10/ 0–5/0
RA (high)	47.53	8.00	59.0	29.5	
SVC	45.00	7.69	55.5	30.5	
IVC	40.83	11.85	86.5	29.5	
Femoral artery	38.51	11.73	86.0	28.0	
Femoral artery oxygen capacity		13.56			

The results indicated (a) pulmonic stenosis with a systolic gradient of 60 mm. Hg, and (b) interauricular septal defect with a rise in O_2 per cent saturation on passing from high to low position in the atrium (in excess of 3 vols. per cent). The interauricular septal defect was confirmed by passage of the catheter through the septal defect and by arterialization of blood at this level. No blood sample could be obtained from the left atrium and, unfortunately, the pressure tracing was damped and unsatisfactory. In addition, the relative unsaturation of the femoral arterial blood would suggest a concomitant right-to-left shunt. The pressure tracing obtained on pull-through from the pulmonary artery to the right ventricle is reproduced (Fig. 3). It is suggestive of an infundibular type of stenosis. The angiocardiogram was technically unsatisfactory.

Surgery was performed on June 19, 1956, by Dr. E. M. Nanson. A left anterior thoracotomy was done. The right ventricle was noted to be enlarged and a harsh systolic thrill was palpated in the pulmonary artery. There was no thrill in the region of the infundibulum. The presence of a pulmonic stenosis was confirmed by passing a cannula via a small incision in the right ventricular wall. A Potts valvulotome was used to cut the valve, which was then dilated with a Potts dilator. This resulted in an irregular beat with numerous ventricular premature systoles. Grossly, the myocardium showed evidence of hypoxia. The heart was permitted to fall back into the usual position and there was immediate relief of the hypoxia.

Postoperatively, the child cried well and moved all extremities. There was marked pallor and some cyanosis of the lips and fingers. Chest x-ray showed that the lungs were well inflated. Respirations were wheezy and rattling. The child was suctioned repeatedly and white mucous was removed from its nasopharynx. Respiratory difficulty continued throughout the night. An attempt at endotracheal suction the following morning resulted in cardiac arrest, and although immediate thoracotomy was carried out and manual massage instituted the child could not be revived.

A.



B.

Fig. 1.—*A*, Roentgenogram in the posteroanterior view is not remarkable. *B*, In the left anterior oblique position, the ventricle is enlarged posteriorly and does not clear the spine. The right ventricle does not appear enlarged in this view.

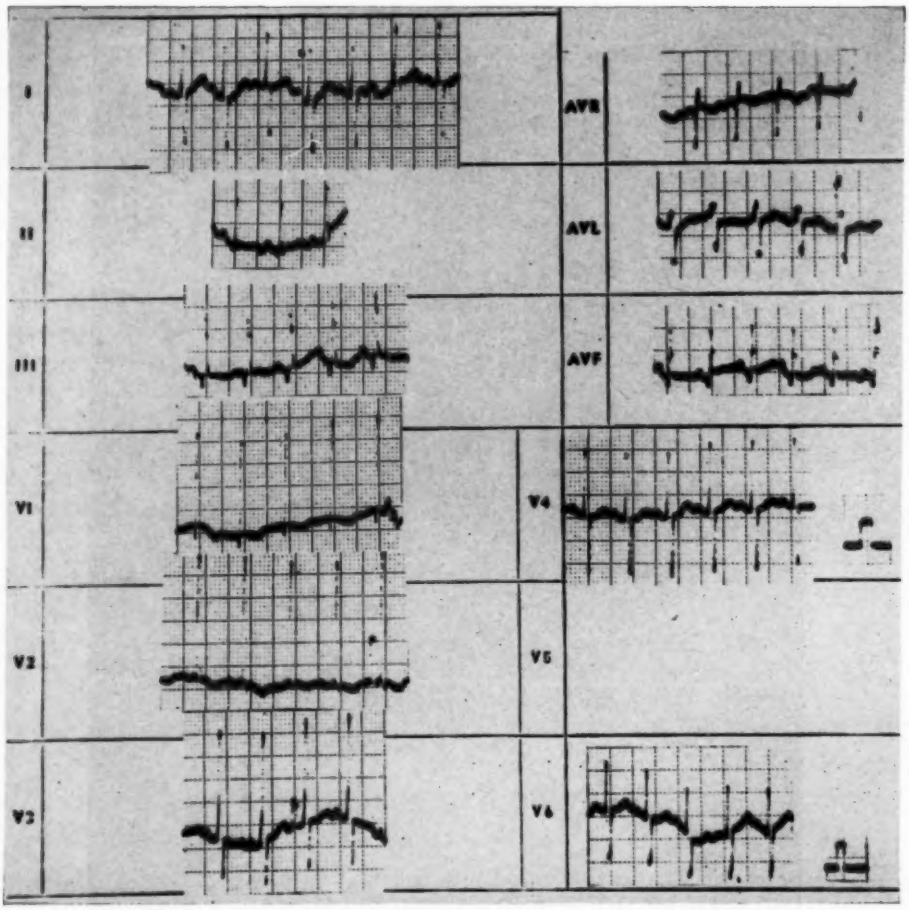


Fig. 2.—The ECG recorded with full standardization in Leads I, II, III, aV_R, aV_L, and aV_F, and and V_1-V_2, and half standardization in V_3, V_4, V_6. The very tall R waves in V_1-V_2 are indicative of RVH, and the deep S waves in V_4 and V_6 suggest LVH. The electrical axis is 90 degrees.

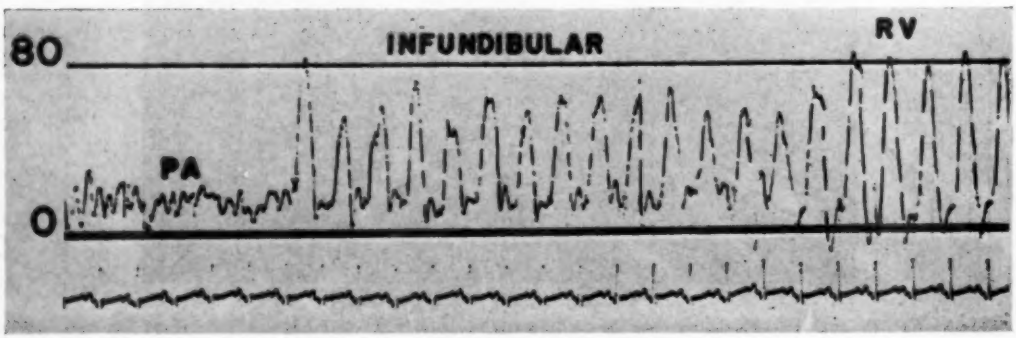
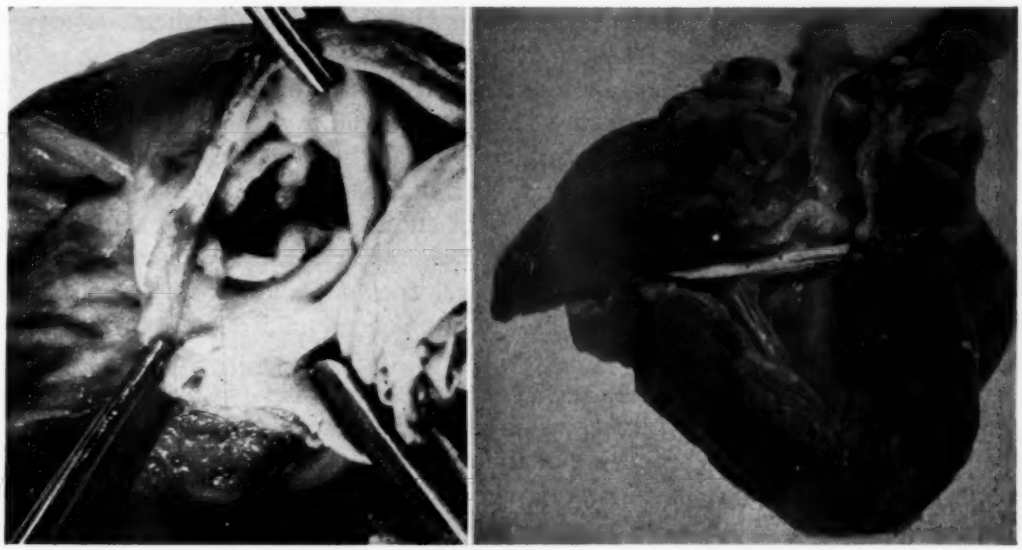


Fig. 3.—Continuous recording of pressure during withdrawal of the catheter from the pulmonary artery into the right ventricle. The middle part of the tracing marked "infundibular" was thought to be due to infundibular stenosis.

Pathologic Findings.—The pathologic findings were of great interest. The heart was grossly enlarged and weighed 95 grams (normal for this age, 39 grams). The right atrium was dilated and there was an interauricular septal defect, foramen secundum in type and fenestrated. The tricuspid valve ring was greatly dilated (circumference 7.0 cm.) and the right ventricle was grossly dilated and hypertrophied (0.4 cm. in thickness). There was thickening and fusion of the 3 pulmonary valve cusps, with narrowing of the orifice. There was a cut in the conical valve in the region of the anterior cusp, which obviously had been produced by the valvulotome (Fig. 4,*A*).

The left ventricle was enormously hypertrophied with a wall thickness of 1.3 to 1.5 cm. The hypertrophy was concentric and the cavity of the left ventricle was much reduced in size. The aortic valve was tricuspid with poorly formed commissures, and the cusps were grossly thickened and fused with a markedly narrowed valve orifice (Fig. 4,*B*). The mitral valve ring was probably of normal size (circumference, 3.5 cm.), but when viewed from above, it appeared small.



A. *B.*

Fig. 4.—*A*, The pulmonic valve is seen from above. The lateral cut made by the Potts valvulotome may be seen. *B*, The thickened conical aortic valve with its narrowed orifice may be seen in this figure. The thickened wall of the left ventricle is shown also.

The valves were slightly thickened and the valve edges nodular and gelatinous, but the chordae appeared normal. The left and right lungs weighed 70 and 100 grams, respectively (expected weight, 35 and 38 grams). There were purplish red patches on their pleural surfaces, and several indurated areas could be felt. The liver weighed 260 grams (normal, 188 grams). Each kidney weighed 35 grams (expected weight, 25 grams).

Microscopically, sections of the aortic valve cusp showed that it was composed of densely packed bundles of fibrous tissue. The lungs, liver, and viscera, all showed evidence of chronic passive congestion.

DISCUSSION

There were a number of unusual features in the investigation of this case which might have directed us toward the correct diagnosis. First was the finding of left ventricular enlargement, on x-ray examination, in the presence of relatively normal right ventricle and left auricle. Second was the presence of a bidirectional shunt at the auricular level in the presence of pulmonic stenosis with a systolic gradient of 60 mm. Hg. Left-to-right shunting is definitely unusual in pulmonic stenosis.

Bing and associates[4] stated that "when there is an atrial septal defect or patent foramen ovale with pulmonary stenosis, the right auricular pressure exceeds that in the left throughout the entire cardiac cycle, resulting in right-to-left shunting only." Several other workers,[5-7] however, have described cases of pulmonic stenosis with atrial septal defect or ventricular septal defect, or both, associated with left-to-right shunting. Left-to-right shunting, however, occurred only when the pulmonary stenosis was mild, and the actual gradient across the pulmonic valve in most cases was less than 40 mm. Hg. In the cases reported by Broadbent and associates[5] the systolic pressure gradients were (in mm. Hg) 122, 27, 31, 35, 22; and in those of Rudolph and associates[6] they were 18, 25, 28, 40, 39, and 45. In this connection, it must be remembered that there may be normally a small pressure gradient across the pulmonic valve. In the presence of increased flow, as with an atrial septal defect, the gradient may be as great as 40 mm. Hg in the absence of any anatomic evidence of pulmonic stenosis.[8]

In the present case the pressure gradient was 60 mm. Hg. It is unlikely that left-to-right shunting would ordinarily occur in the face of such a high right ventricular pressure, since it is the resistance to filling of the ventricles which ordinarily determines the direction of shunts at the atrial level. Thus, Rudolph and associates[6] concluded that a pulmonary stenosis of severe degree, with a valve resistance in the systemic range, does not allow for a left-to-right shunt through an associated defect, and may be accompanied by a right-to-left shunt.

In the present case, the partial relief of the pulmonic stenosis by valvulotomy probably resulted in a rise in the volume of the left-to-right shunt because of reduction in resistance to emptying of the right ventricle. The increase in pulmonary flow and pressure in the presence of continued obstruction to left ventricular outflow might well have been responsible for the pulmonary edema found at autopsy.

SUMMARY AND CONCLUSIONS

A case of combined valvular, pulmonary, and aortic stenosis of congenital origin is described. Hemodynamic findings of a left-to-right shunt at the atrial level in the presence of pulmonic stenosis of severe degree should make one suspect some impediment to aortic outflow. Femoral pressure tracings might have helped in the diagnosis of the aortic valve lesion.

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PROLONGED MYOCARDIAL DISEASE DUE TO BERIBERI, WITH NECROPSY AFTER 18 YEARS

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THE following case is presented to illustrate prolonged congestive heart failure and ultimate death following acute beriberi heart disease. Not only is the case of interest from this point of view, but also because of the confusion in anatomic diagnosis which resulted from this obscure disease of the myocardium.

CASE REPORT

A 33-year-old Negro woman was first admitted to the Cincinnati General Hospital in 1933, after sustaining a fracture of the left tibia and fibula. She had had previously an undetermined amount of antisyphilitic therapy. A surgical resident described the heart as slightly enlarged to the left, with a short systolic murmur near the base and a snapping second sound. The Wassermann was strongly positive.

In subsequent years she drank heavily and her diet was poor. She entered the hospital for the second time on July 3, 1937. During the 4 months before her admission, she developed the following symptoms, in the order listed: shortness of breath on exertion, darkening of the skin around the eyes, soreness of the mucous membranes of the mouth, generalized weakness, ankle edema, and painful, pigmented areas on the hands and wrists.

Physical examination revealed: temperature 98.6°F.; pulse 132; respiration 24; blood pressure 118/85 mm. Hg. There was pellagrous dermatitis of the hands, wrists, forearms, and periorbital region.* The oral mucous membranes were red, and the gums bled easily. There was no venous distention. The heart was markedly enlarged, with the apex impulse 12 cm. to the left of the mid-sternal line in the fifth intercostal space. There was sinus rhythm without murmurs. A diastolic gallop was present, and the pulmonary closure was louder than the aortic. The liver was slightly enlarged and there was a trace of pretibial edema. A neurologic consultant (Dr. Charles D. Aring) found evidence of mild nutritional neuritis in her legs.

The laboratory data included: RBC 2.81 mil.; Hgb. 9 Gm.; WBC 6,900 (neutrophils 40 per cent, lymphocytes 58 per cent); urinalysis, negative; Kahn, 2 plus; serum proteins 7.24 Gm.; and N.P.N. 25 mg. per cent. Chest x-ray showed the heart enlarged in all diameters, and bilateral peribronchial infiltrate probably secondary to cardiac decompensation. Numerous electrocardiograms showed only nonspecific T-wave changes, interpreted as "myocardial damage." On July 8, 1937, the circulation time (NaCn) was 23.8 seconds, and the venous pressure, 15 cm. of water. At no time was she thought to show "high output failure."

She was treated with a high-caloric, high-vitamin diet, with supplementary brewer's yeast. Although the skin lesions slowly cleared, her course otherwise was stormy, being complicated by lobar pneumonia and venous thrombosis in two extremities. Tachycardia, cardiomegaly, and gallop rhythm persisted throughout her hospitalization, unaffected by digitalization and intravenous crystalline vitamin B_1. Bismuth and iodides were administered for 3 months as further antisyphilitic therapy, and she was discharged, ambulant and improved, on Nov. 13, 1937.

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Received for publication March 12, 1957.

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*A photograph of this patient's skin lesions appears in an article by Bean, Spies, and Vilter.[1]

The most prevalent diagnosis on this admission was beriberi heart disease, but the failure to respond to adequate dietary and vitamin therapy led to such diagnoses as congestive myocarditis, syphilitic myocarditis, syphilitic coronary ostial stenosis, tuberculous pericarditis, and degeneration of the vagi due to thiamin deficiency.

On Aug. 19, 1938, she was admitted for the third time because of symptoms of digitalis intoxication. She had continued to drink and had taken digitalis only sporadically. Because of dyspnea and ankle edema, she had been digitalized at another institution just prior to her transfer to the Cincinnati General Hospital. Pertinent physical findings included: pulse 55, and blood pressure 170/110 mm. Hg. The heart was enlarged to right and left, and there was a bigeminal rhythm. A harsh systolic murmur at the apex was transmitted over the entire precordium. A gallop rhythm was heard intermittently. The liver was slightly enlarged but there was no edema. Chest x-ray, compared to films of the previous admission, showed some decrease in cardiac size, with prominent hilar and peribronchial markings. The electrocardiogram showed premature ventricular contractions with bigeminal rhythm, left axis deviation, and myocardial damage.

Digitalis was withheld and quinidine administered, with disappearance of the arrhythmia. The digitalis dose was then regulated. The patient suffered attacks of paroxysmal nocturnal dyspnea, and the cardiac findings remained unchanged. Under strict observation she was kept on a vitamin B-free diet from Aug. 19, 1938 to Sept. 27, 1938, without any aggravation of her cardiac symptoms, although she did break the diet on several occasions. She was discharged ambulant on Oct. 11, 1938.

The possibility of hypertensive heart disease was suggested on this admission for the first time. The absence of change with vitamin deprivation was interpreted as evidence against beriberi heart disease. All agreed that her prognosis was poor.

Again the patient failed to take her digitalis, and on Dec. 5, 1938, she came to the hospital for the fourth admission because of increasing symptoms of congestive failure and abdominal swelling. Her blood pressure was 134/118 mm. Hg. There were a few râles at both lung bases. The heart was still enlarged, with a gallop rhythm. The loud apical systolic murmur persisted. The liver was enlarged and pulsating, and ascites was present. The tip of the spleen was palpable. There was marked edema of the legs and sacrum.

Again no improvement was noted after the administration of thiamin, this time by the intramuscular route, and she was therefore digitalized. Blood pressure recordings ranged from 130 to 140 mm. Hg systolic and from 90 to 100 mm. Hg diastolic. The serum proteins were 5.4 Gm. She improved little until the administration of mercurial diuretics evoked a diuresis. Then her edema decreased markedly, but liver pulsations continued and some ascites persisted. On March 1, 1939, she left the hospital against advice.

Now the diagnoses included severe myocardial disease with tricuspid and mitral insufficiency, organic mitral insufficiency, nutritional cirrhosis, syphilitic myocarditis, and infectious myocarditis of unknown etiology.

From 1939 to 1951, the patient attended another clinic, nearer her home, where she continued to receive digitalis and mercurial diuretics, but further hospitalization was not necessary.

In 1951, she was admitted to the surgical service for her fifth admission, for excision of a fistula-in-ano. Cardiomegaly was present by physical examination and by x-ray, but there was no evidence of congestive failure. A Grade 1 precordial systolic murmur was described.

In 1954, she visited the outpatient department of the Cincinnati General Hospital, because of dyspnea. Persistent cardiomegaly was noted, with a loud apical systolic murmur and an accenuated pulmonary closure sound. The liver was enlarged and tender. There was no edema. A radioactive iodine uptake study showed 42 per cent uptake in 24 hours.

Her sixth and final admission, on Sept. 5, 1955, was necessitated by increasing dyspnea, orthopnea, and edema for from 1 to 2 months. She had been confined mainly to bed except for biweekly trips to a nearby clinic to receive a mercurial diuretic. The examination showed: pulse 120, and blood pressure 165/100 mm. Hg. The neck veins were pulsating. The heart was markedly enlarged in all directions, and there was coupling of the heart beats. There was a Grade 3 apical systolic murmur transmitted to the back, and a Grade 2 aortic systolic murmur. The pulmonary closure sound was accentuated. A few râles were heard at the left lung base. The liver was enlarged, tender, and pulsating, and there was moderate pretibial edema. Chest x-ray showed

marked cardiomegaly with pulmonary congestive changes. The electrocardiogram showed premature ventricular contractions with bigeminal rhythm, auricular fibrillation, and left ventricular hypertrophy.

Digitalis was withheld for 9 days while the patient's symptoms were poorly controlled with mercurial diuretics, aminophylline, and Demerol. Premature ventricular contractions continued. From September 14 to September 16, she was given 3 mg. of Gitaligin. On the morning of September 19, she was found unresponsive, with a rapid pulse and increased dyspnea. An electrocardiogram showed auricular fibrillation with multifocal premature ventricular contractions and runs of ventricular tachycardia. Oral potassium chloride 3 Gm. was given immediately, and a dose of 4 to 6 Gm. per day was continued for the next 5 days. The premature ventricular contractions disappeared, and on September 28, a daily maintenance dose of 0.5 mg. Gitaligin was resumed. She continued to retain fluid, and had frequent attacks of dyspnea and right upper quadrant pain due to hepatic engorgement. Diuretics became less and less effective. At 4:40 A.M. on Oct. 18, 1955, she complained that her hands and feet felt numb. Shortly thereafter she threw back her head and respirations ceased.

Diagnoses on the last admission included myocardosis of unknown etiology, cor pulmonale secondary to multiple pulmonary infarcts, and rheumatic mitral insufficiency.

Autopsy.—The autopsy was performed by Dr. Franklin H. Cox 5 hours after death. The material was reviewed by Dr. Edward A. Gall of the Department of Pathology.

The heart was strikingly enlarged, weighing 530 grams. Despite considerable dilatation of all chambers, and in particular the right atrium, the left ventricle measured 18 mm. in thickness and the right, 7 mm. No valvular or endocardial abnormalities were detected in the gross. The coronary arteries were the seat of a moderate degree of focal arteriosclerosis, with little intrusion upon the lumens. A moderate amount of patchy atheroma formation was also manifest in the larger branches of the pulmonary artery.

Sections of heart procured from 7 sites revealed variable but widespread microscopic alterations. Myocardial fibers were narrow and attenuated and exhibited spotty vacuolation which did not stain for lipid. There was much fraying and fragmentation in excess of that ordinarily encountered as artefact. In many areas fibers were separated by what was presumed to be precipitated edema fluid; in other foci there was a fine interstitial deposit of fibrillar collagen. High in the interventricular septum was a small (1.0 cm.) cicatrix with complete replacement of muscle. No attendant vascular lesion was detected. A rare interstitial collection of leukocytes was observed; there was no recent necrosis of muscle.

The endocardium revealed an occasional plaque resulting from fibrcelastic thickening. There was no evidence of recent proliferative or inflammatory activity.

Although not noted grossly, the finer branches of the pulmonary artery contained multiple emboli, some of which were in the process of organization. These were not of sufficient number or duration to justify consideration of chronic cor pulmonale. A recent infarct (3.0 cm.) was present in the left upper lobe. In the right upper lobe was a circumscribed caseous nodule (2.5 cm.) representing a noncontributory tuberculous focus.

The liver was neither fatty nor cirrhotic, but exhibited severe acute passive congestion obviously attributable to agonal right heart failure. The findings in the brain and other viscera were not pertinent.

A current collaborative study in the Department of Medicine and Pathology is concerned with cardiac lesions observed at necropsy in patients who had clinical evidence of long-standing beriberi heart disease, or who had such an episode in the past with apparent subsidence of manifestations. The morphologic findings in the present case are indicative of prolonged and continuing degenerative myocardial alteration of nonspecific nature. This form of myocardosis is identical with that observed in many of the cases in the beriberi group under investigation.

DISCUSSION

There seems to be little doubt that the initial episode of cardiac decompensation represented acute beriberi heart disease. The patient conformed to the diagnostic criteria suggested by Blankenhorn[2] in 1945. It is now accepted that

failure to respond to thiamin does not exclude this diagnosis. However, a course as prolonged as that of our patient must be quite rare. Standard textbooks of medicine and cardiology[3,4] state that occasionally the myocardial changes of thiamin deficiency are irreversible, and recovery may be incomplete and followed by recurrent bouts of congestive heart failure.

I made no wide search but did find a somewhat similar patient reported by Alleman and Stollerman.[5] They described two Americans who developed beriberi heart disease while prisoners-of-war in Japan. While one patient responded well to treatment, the other continued to drink heavily, and because of a number of food fetishes, ate, at times, an inadequate diet. He experienced his first recurrence of congestive heart failure about 3 years after the onset of beriberi, and died about 4 years after onset in intractable congestive failure. At autopsy the myocardial fibers showed extensive cloudy swelling, loss of striation, fragmentation, and fatty degeneration with replacement fibrosis. There was interstitial edema and nuclear degeneration with some cellular infiltration. The authors believed these changes to represent the the irreversible damage of a chronic beriberi heart.

The presence of a murmur and possible cardiac enlargement in our patient in 1933, raises the possibility of another type of heart disease antedating the onset of beriberi. However, no x-ray was taken at that time to confirm the cardiomegaly, and evidence of other types of heart disease was lacking at autopsy. The prominent cardiac findings were those of myocardosis.[6] It was the opinion of the pathologist, Dr. Edward A. Gall, that these changes probably did fall into the category of residua of beriberi. It is recognized that this conclusion cannot be made with certainty, but the presumption seems reasonable. Therefore, it appears that as a result of the severe nutritional deficiency, the patient suffered irreversible myocardial damage which expressed itself in the subsequent 18 years as continued congestive heart failure of varying degree.

SUMMARY

A case of beriberi heart disease is presented in which the acute episode was followed by chronic and recurrent congestive heart failure over a period of 18 years. At autopsy, the histologic changes in the heart were those of myocardosis, without other apparent cause for the heart disease. It seems most likely that these changes represent residua of beriberi. The number and variety of the clinical diagnoses well illustrate the confusion which results from such primary myocardial disease.

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CARDIAC CONTUSION CAUSED BY THE USE OF A JACKHAMMER

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WE RECENTLY observed a patient who had an episode of paroxysmal auricular fibrillation, and serial S-T-segment and T-wave changes on the electrocardiogram, closely following the improper use of a jackhammer. The time relationship suggested that a cardiac contusion had probably been produced. Because we were unable to find a report in the literature of a clinical cardiac contusion produced in a similar manner, we present this case.

CASE REPORT

This 33-year-old Negro construction worker had been quite healthy with no history of heart disease prior to admission to the hospital. On Dec. 8, 1955, he was using a 90 pound pneumatic jackhammer to break concrete under a building, in a space with little head room. He was unable to stand erect and press down on the handle of the jackhammer in the usual manner. Instead, he pressed his chest against the handle in order to push it down. His anterior chest rested on the handle at approximately the level of the third intercostal space. He used the jackhammer in this manner for approximately 2 hours. Although he had used a jackhammer for years, this was the first time he had used it in this way.

At 2 A.M. the following day he was awakened by a fluttering and pounding sensation in his chest, unlike anything he had ever experienced. He noted that his pulse was very fast. He had no pain of any kind. Because the fast pulse persisted, he came to the hospital.

Examination at 3 A.M. revealed a very well-developed, moderately obese, healthy-appearing young Negro. He was 6 feet 1 inch in height and weighed 260 pounds. His pulse rate was 130 per minute and irregular, with a pulse deficit. His blood pressure was 190/90 mm. Hg. There was a soft, blowing, Grade 2 systolic apical murmur. The remainder of the physical examination was normal. An electrocardiogram revealed auricular fibrillation with a ventricular rate of 125 (Fig. 1,*A*). The T waves were low in the limb leads, V_5 and V_6, and diphasic in Leads V_3 and V_4.

He was given 3 grains of Amytal sodium. Six hours later, a sinus rhythm was present (Fig. 1,*B*). There was elevation of the S-T segments in Leads $V_{2\text{-}4}$. He was asymptomatic at this time. However, because of the elevation of the S-T segments, he was kept at bed rest and observed. Three days after admission, an electrocardiogram revealed return of the precordial S-T segments to normal. Five days after admission, there was inversion of the T waves in Leads V_4 and V_5 (Fig. 1,*C*). The heart size was within normal limits on the chest x-ray. His blood pressure averaged 150/80 mm. Hg while in the hospital. Routine laboratory data were normal. He remained asymptomatic and was discharged from the hospital on Dec. 16, 1955.

Following discharge, he slowly increased his activities. He felt well except for a fluttering sensation in the chest, noted on resting after a long walk. This was accompanied by a fast pulse which would gradually slow to normal over a period of 5 minutes. These episodes were present during the following 7 weeks. He had no chest pain or dyspnea at any time. On Jan. 10, 1956, the T waves were upright (Fig. 1,*D*). In February, he had only an occasional sensation of palpi-

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Received for publication March 15, 1957.

tation, on first awakening or on resting after exercise. He had no episodes of tachycardia at this time. On February 28 a Master's test was negative. There was no significant change in the limb leads at any time (Fig. 1,*E*). Three months after the initial episode, he returned to work without difficulty.

A follow-up 5 months after his return to work revealed that pressure on his anterior chest still elicited some tenderness. He also reported several vague episodes of a rapid pulse persisting for 3 or 4 minutes. These were never observed by us.

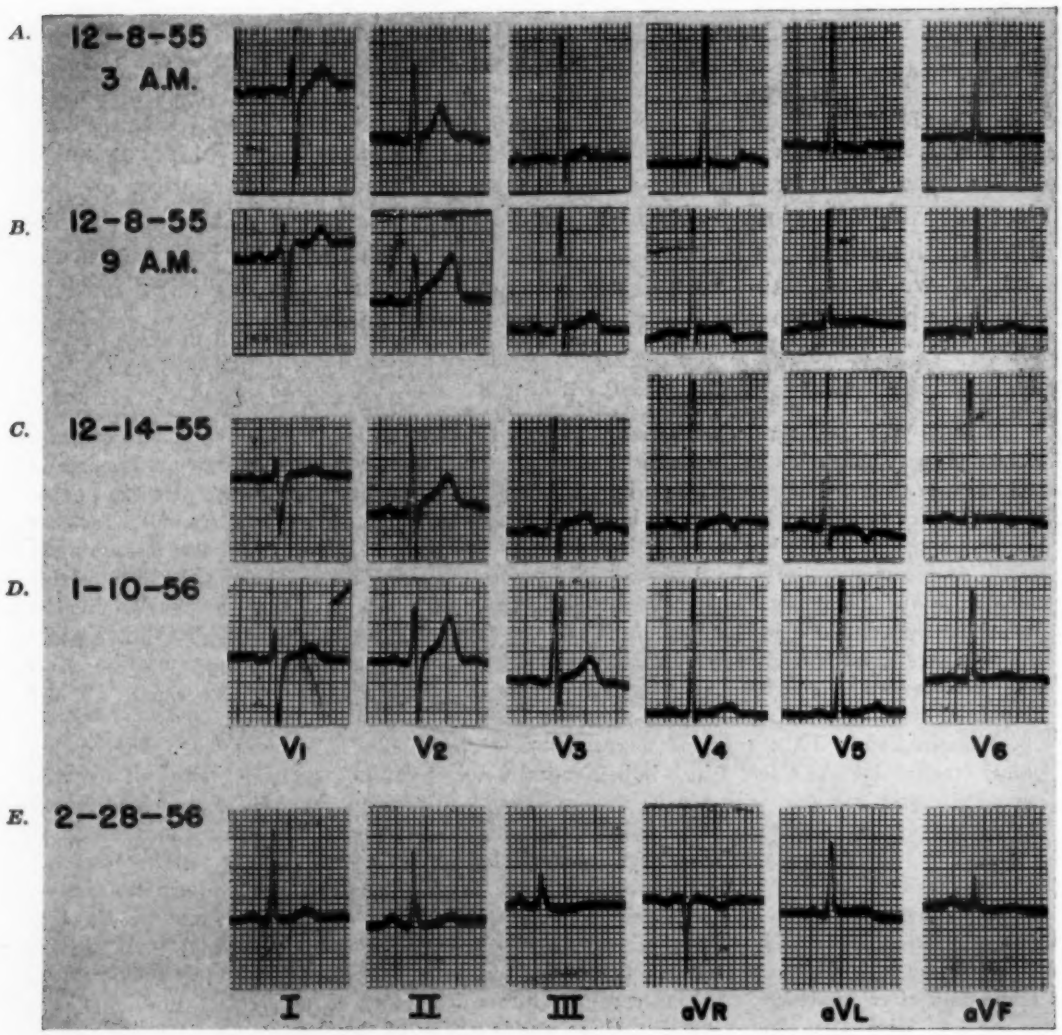

Fig. 1.—Serial precordial electrocardiographic leads show the auricular fibrillation on the morning following the improper use of the jackhammer, *A*; elevated S-T segments, *B*; inverted T waves, *C*; and a normal appearance, *D*. The limb leads, *E*, showed no significant change at any time.

DISCUSSION

Many types of blunt nonpenetrating injury to the chest are recognized as causing cardiac contusion.[1-4] These include blows to the chest by a fist, a club, a heavy falling object, or a ball traveling at high speed; a fall from a great height; kicks by a horse; compression of the chest between two moving objects; blast

injuries; and the "steering wheel injury" in an automobile accident. Clinical manifestations of these injuries include chest pain, weakness, palpitation, arrhythmias, congestive heart failure, cardiac enlargement, and the effects of pericarditis and hemopericardium. Auricular fibrillation is the most common important arrhythmia. Electrocardiographic abnormalities include elevation and depression of the S-T segments and inversion of the T waves. Pathologic effects of such trauma include pericardial, subepicardial, myocardial, and subendocardial hemorrhage; fibrinous pericarditis; hemopericardium; laceration of the pericardium; and rupture of any of the heart chambers.

The occurrence of an episode of paroxysmal auricular fibrillation with elevation of the S-T segments and inversion of the T waves, shortly after the use of a jackhammer in the manner described, strongly suggests that a traumatic pericarditis was produced. The type and duration of electrocardiographic abnormalities could not be attributed to tachycardia alone. The symptoms and the times of onset, duration, and disappearance of the signs and symptoms in this case are similar to those in other mild clinical cases of cardiac contusion, and to those in experimental studies. Six to 12 hours usually intervene before an indication of pericardial involvement manifests itself.[1] Most abnormalities on the electrocardiogram disappear in a month.[2] In dogs subjected to relatively moderate blows to the chest, the most frequent cardiac finding is pericardial injury.[3] It would appear quite likely that prolonged close contact of the chest with the vibrating handle of a jackhammer could produce a pericardial or subepicardial hemorrhage, or a fibrinous pericarditis.

This case has several unique features. We did not find a report of any other case of cardiac contusion caused by the use of a jackhammer. Of greater interest, all other clinical cases of cardiac contusion, of which we are aware, were caused by a single severe injury, whereas the contusion in this case would appear to have been caused by the repeated, less severe blows of the jackhammer, over a prolonged period.

SUMMARY

A case is presented in which an episode of paroxysmal auricular fibrillation with elevation of the S-T segments and inversion of the T waves occurred soon after prolonged close contact of the anterior chest with the vibrating handle of a jackhammer. It is felt that a traumatic pericarditis was produced. We were unable to find a report of a cardiac contusion caused by this means. In contrast to other clinical cases of cardiac contusion which were caused by a single severe blow, the contusion in this case would appear to have been caused by repeated, less severe blows, over a prolonged period.

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TRAUMATIC RUPTURE OF THE INTERVENTRICULAR SEPTUM

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THE occurrence of cardiac damage following a nonpenetrating blow to the chest wall is well known. The pericardium or myocardium may be injured and the valves or their attachments may be torn. The myocardium may suffer perforation involving the wall of one or more chambers, or of the septa. Perforation of the interventricular septum is less frequent than perforation of the wall and occurred only 13 times in 152 cases of rupture of the heart collected by Bright and Beck.[3] The purpose of this paper is to report a patient with traumatic rupture of the interventricular septum proved by cardiac catheterization and followed over a period of 1½ years.

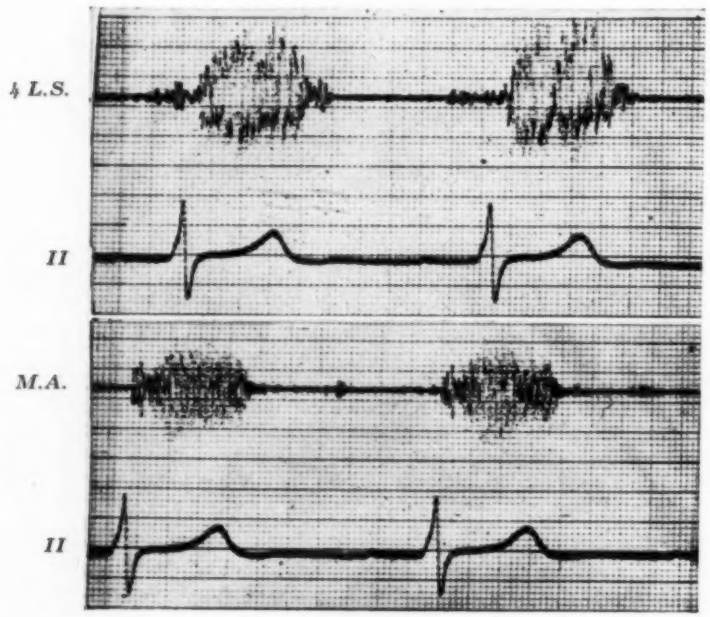

Fig. 1.—Blowing systolic murmur, recorded from the fourth intercostal space at the left sternal edge (4 *L.S.*) and mitral area (*M.A.*). Short presystolic murmur shown in the fourth intercostal space at the left sternal edge (4 *L.S.*).

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Received for publication March 20, 1957.

CASE REPORT

The patient, a 32-year-old farmer, had been in good health until August, 1954. In 1946, he had a medical check-up required for obtaining life insurance, and was told that his health was excellent. In 1950, he had another physical examination before an operation for open repair of an accidental fracture of the humerus. Nothing abnormal was noted.

On Aug. 19, 1954, while working, he was kicked on the precordium, by a horse. He was knocked to the ground and remained unconscious for about 10 minutes. He complained then of sharp precordial pain aggravated by respiration. There was no open wound on the thorax. After 2 days of bed rest the patient tried to resume his activity, but complained of dyspnea on the slightest exertion. A few days later, his private physician noted the appearance of ankle edema, hepatomegaly, and crepitant râles at the bases of the lungs posteriorly. The signs of circulatory failure increased during the following days and he, therefore, was transferred to a nearby clinic. The circulatory failure was interpreted to be the result of traumatic mitral insufficiency. Treatment consisted in bed rest, salf-free diet, and digitoxin.

The patient was first admitted in our clinic on Dec. 20, 1954, for cardiac evaulation. Upon admission his only complaint was of dyspnea on exertion. Physical examination revealed a well-nourished young man in no acute distress. The pulse was regular at 76 per minute, and the blood pressure was 125/85 mm. Hg in both arms. The lungs were clear to percussion and auscultation.

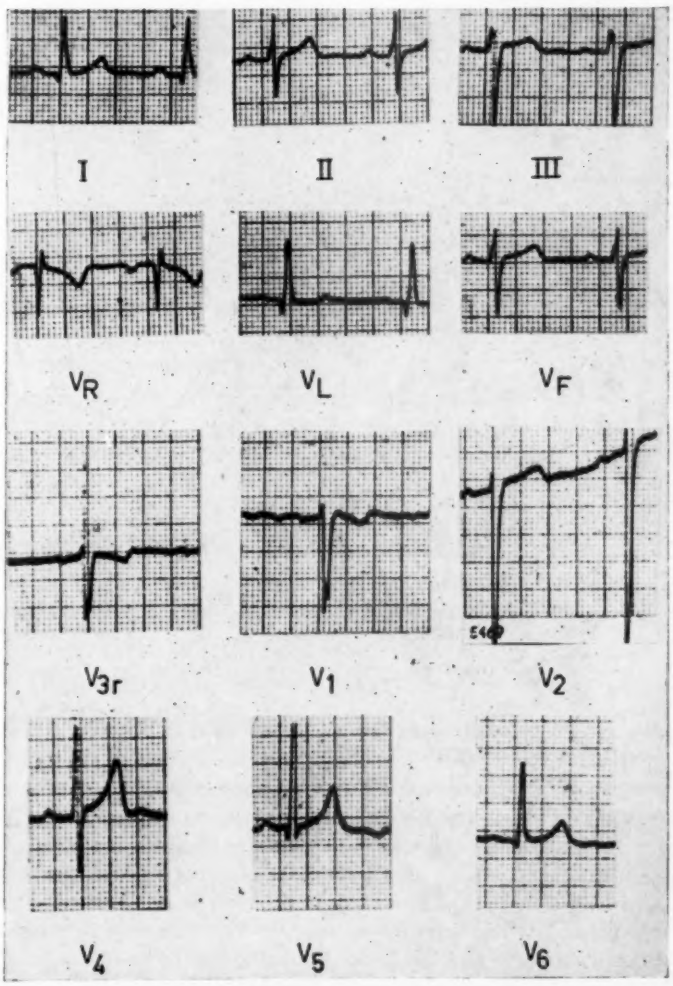

Fig. 2.—Electrocardiogram showing a left axis deviation and positive Sokolow-Lyon index.

The heart was slightly enlarged on percussion. There was a systolic thrill in the third and fourth left intercostal spaces. In the same area there was a very loud blowing holosystolic murmur (Grade 6), transmitted to the whole precordium and to the back; there was also a short presystolic murmur, as can be seen on the phonocardiogram (Fig. 1). The liver was not palpable. The routine laboratory examinations were normal. Arm-tongue circulation time with magnesium sulfate was 17 seconds. Vital capacity was 3.6 L., and residual air was normal. An electrocardiogram showed slightly prolonged P-R (0.21 sec.), a left axis deviation, and positive White-Bock and Sokolow-Lyon indices. The T waves were low in Lead aV_F (Fig. 2). The chest roentgenogram revealed enlargement of the cardiac silhouette, especially of the right ventricle. There was slight clouding of the lungs due to passive congestion, obliteration of the right costophrenic angle, and accentuation of the interlobar fissure (Fig. 3). Fluoroscopic examination showed hilar dance.

Cardiac catheterization was performed through the right antecubital vein, after an unsuccessful attempt on the left side. The data obtained during catheterization are given in Table I.

TABLE I. RESULTS OF CARDIAC CATHETERIZATION

LOCATION	DECEMBER 1954					APRIL 1956				
	PRESSURE (MM. Hg)			OXYGEN		PRESSURE (MM. Hg)			OXYGEN	
	S	D	M	CONTENT (VOL. %)	SATURATION (%)	S	D	M	CONTENT (VOL. %)	SATURATION (%)
Superior Vena Cava				10.1	51				11.2	58
Right Auricle			10	10.3	54			6	11.8 11.4	61.5 59
Right Ventricle	72	4		12.2 12.1	64 63	63	0	28	13.3 17 15.6	69 88 81
Pulmonary Artery	68	23	43	14.8 15.2	78 80	62	13	38	15.1 15.– 15.–	78.5 78 77.5
Pulmonary Artery Wedge Pressure	35	15	20			37	13	18	18.5	96
Brachial Artery				17.5	92	120	77	100	18.5 18.6	96 96.5
	Aortic Bloodflow : 4.73 L./min. Pulmonary Bloodflow: 13.6 L./min.					6.59 L./min. 18.7 L./min.				

There was a significant increase of about 2 volume per cent in O_2 saturation between the right auricle and the right ventricle. There was also a difference of saturation between right ventricle and pulmonary artery. The right ventricular, pulmonary arterial, and pulmonary artery wedge pressures were elevated. Pulmonary arteriolar resistance was normal. The shape of the pulmonary artery wedge pressure was suggestive of mitral insufficiency (see subsequent discussion). The pulmonary output, calculated by the Fick principle, was 13.6 L. per minute, and the peripheral output 4.73 L. per minute. These data were interpreted to represent an interventricular septal defect with a possibility of mitral insufficiency. The difference in saturation between right ventricle and pulmonary artery were interpreted as being due to uneven mixing in the lower part of the right ventricle (no sample was obtained in the outlet tract of the right ventricle).

The patient was discharged and advised to continue with rest, salt-free diet, and digitoxin. The prognosis was thought to be poor.

The patient was seen again in April 1956, about 1½ years later. He had been resting and was still on a salt-free diet. He still complained of dyspnea on exertion and of intermittent ankle edema. Physical examination showed the same results as during the first admission. The electrocardiogram was unchanged from the previous record. Roentgenography showed a slight decrease

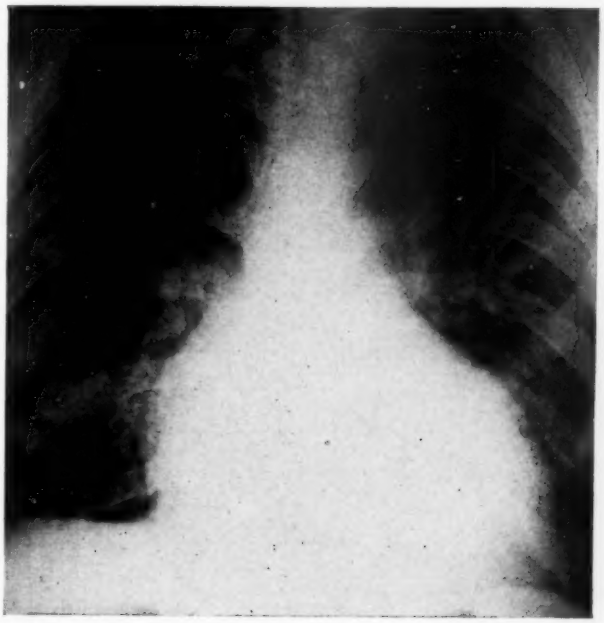

Fig. 3.—Chest roentgenogram illustrating cardiac enlargement and hilar congestion.

of the cardiac size, but hilar dance was still visible on fluoroscopy. A further catheterization was performed and showed approximately the same data as the first time (Table I). There was again a significant difference in O_2 saturation between right auricle and ventricle. The patient was discharged with medical treatment.

COMMENT

Two aspects of this case make it worth-while to report. Traumatic rupture of the interventricular septum is rare and few cases confirmed by catheterization have been reported. Secondly, the development of open heart surgery will now permit successful correction of this defect. Hence, the diagnosis of these cases is now of more than academic interest; such cases will soon be classified as a reversible and curable form of heart disease.[2]

Pollock[10] reported a case of isolated traumatic rupture of the interventricular septum in 1952, and in a review of the literature could collect only 12 cases proved at autopsy. More recently, Leonard[7] reported a similar case associated with rupture of an aortic valve.

Experimental work suggests that a very heavy blow is necessary in order to rupture the heart: in addition to the force, the direction of the blow, and the phase of the cardiac cycle in which it is sustained are of importance; the heart seems more vulnerable in systole.[3]

The septal tear usually occurs near the apex, thus explaining the absence of conductional impairment after rupture. The size of the tear is variable and seems the most important factor determining the length of survival after injury.

The clinical picture after traumatic rupture of the interventricular septum is typical and the diagnosis is suggested by characteristic physical findings. The signs and symptoms are the same as those described by Nareff,[8] Sayer,[11] and Zucker[14] in interventricular septum rupture following myocardial infarction. Shock is often present initially, followed by complaints of dyspnea, orthopnea, and sometimes hemoptysis. A systolic thrill is usually palpable along the left sternal border in the third and fourth intercostal spaces. Auscultation

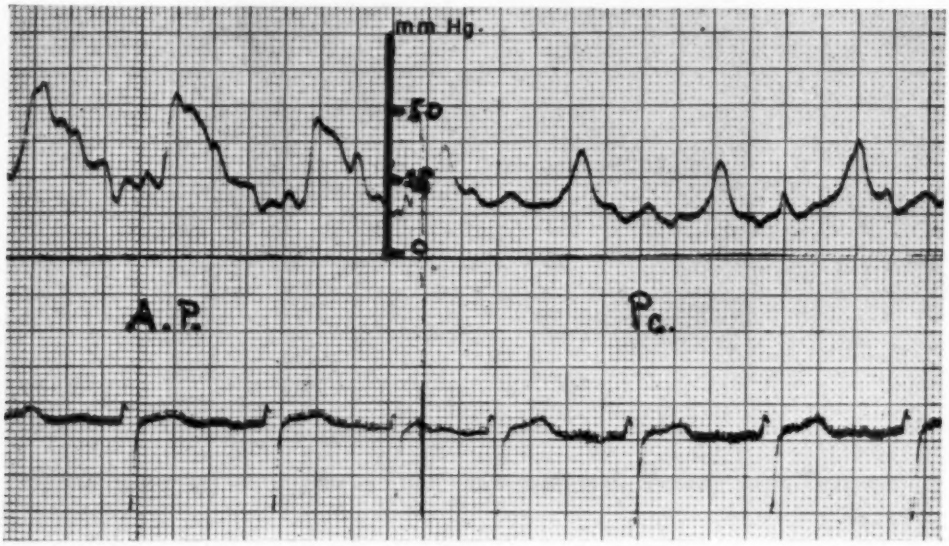

Fig. 4.—Pressure curves recorded (simultaneously with Lead III of electrocardiogram) in the pulmonary artery (*A.P.*) and in the "pulmonary capillary" (*Pc.*). The morphology of the "pulmonary capillary wedge pressure" is suggestive of mitral insufficiency.

reveals a harsh systolic murmur maximal in this area but audible over the whole precordium. There also may be a diastolic murmur along the left sternal border, indicating a functional insufficiency of the pulmonary valve. During the first days after the rupture, there may be slight fever and leukocytosis. Patients who survive show mainly a clinical picture of right-sided heart failure with venous and hepatic congestion. They usually display an electrocardiographic pattern of right ventricular hypertrophy with right axis deviation, signs of right strain in the precordial leads or even right bundle branch block. The present case was unusual in that there were early signs of left ventricular hypertrophy without changes in S-T and T waves.

The results of cardiac catheterization proved interesting. The validity of the results obtained at the first catheterization was confirmed by the second study. The diagnosis of interventricular septal defect with left-to-right shunt was established conclusively by the increase in the oxygen content between right atrium and right ventricle. In addition, at both catheterizations the

shape of the pulmonary capillary wedge pressure was suggestive of mitral insufficiency (Fig. 4). Indeed, we found enlargement, anticipation, and excessive height of the v wave; those signs have been described as characteristic of mitral insufficiency by many authors.[1,4,5,6,12,13] More recently, Owen and Wood[9] have suggested that in mitral insufficiency the time taken for the v descent is shortened, the most stable expression of this being the quotient of calculated rate of fall (mm. Hg per second) divided by the height of the preceding v wave. This quotient increases with the degree of mitral insufficiency present. Whereas in pure mitral stenosis it amounted to 0.81, in mitral insufficiency they found a mean of 3.1. In our case the y descent was very steep and the quotient was 3.16.

In this case the diagnosis of mitral insufficiency could not have been made without catheterization, since the clinical features and cardiovascular alterations were overshadowed by those of the interventricular septal defect. When laceration of the mitral valve occurs alone, there is usually a musical systolic murmur and often a thrill at the apex. Isolated rupture of a chorda tendinea of the mitral valve can be recognized also by a sonorous musical murmur at the apex, usually without a thrill. In both, tear of a cusp or rupture of a chorda of the mitral valve, pulmonary edema is the predominant clinical feature. The electrocardiogram develops left axis deviation and there is roentgenographic enlargement of the left atrium.

The prognosis depends mostly upon the size of the defect; in the 4 cases (reported by Pollock) who survived several years, the septal perforation was less than 2 cm. in diameter.

SUMMARY

A case is reported in which traumatic rupture of the interventricular septum and mitral insufficiency were proved by cardiac catheterization.

The patient was still alive 1½ years after the episode occurred.

The diagnosis and physiopathology of this condition are discussed.

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REVERSED RECIPROCAL RHYTHM

LOUIS A. SOLOFF, M.D.,* AND JACOB ZATUCHNI, M.D.**

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AN ARRHYTHMIA characterized by a return to the ventricle of an atrial beat which arose in the atrioventricular node is called reciprocal rhythm.[1] It is almost universally held that reciprocal rhythm cannot occur in the presence of an atrial pacemaker. Scherf and Schott[2] actually incorporate an absence of an atrial pacemaker in their definition of reciprocal rhythm. On the other hand, Moe, Preston, and Burlington[3] presented strong experimental evidence that reciprocal rhythm originating in the atrium does occur and that there is no reason that it should not occur clinically. Katz and Pick[4] have coined the term "reversed reciprocal rhythm" for this possibility.

We present herein the first clinical electrocardiogram, so far as we are aware, which fulfills the criteria for a diagnosis of reversed reciprocal rhythm.

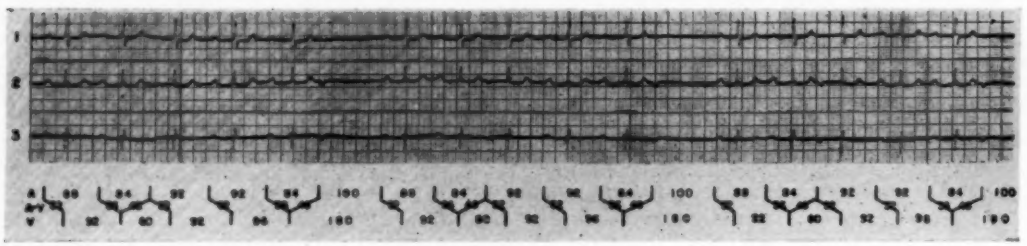

Fig. 1.—Electrocardiogram on Dec. 17, 1956, showing Leads I, II, and III, which were recorded simultaneously. Sinus rhythm is present at a cycle length predominantly of 0.92 second. The first P-R interval is 0.32 second. The second P wave is identical with the first one but has a longer P-R interval (0.36 second). The third P wave, hereafter called P′, is isoelectric in Lead I, and inverted in Leads II and III. The R-P′ interval is 0.48 second. This P′ is followed, after a P′-R interval of 0.32 second, by a premature ventricular complex identical with the other ventricular complexes. This premature ventricular complex is followed by an R-R interval of 0.92 second. The second P′ wave occurs after a ventricular cycle having a length of 0.96 second and is not followed by a ventricular complex. The R-R interval containing this P′ wave is 1.80 seconds, exactly twice the dominant cycle length minus the difference in the P-R intervals. The findings are then repeated. The electrocardiographic arrhythmia is interpreted as showing reversed reciprocal rhythm and blocked forward conduction of a retrograde-conducted impulse in the presence of sinus rhythm, first and second degree (Wenckebach) heart block with grouping formation.

CASE REPORT

A 37-year-old woman was admitted to Temple University Hospital in labor. Delivery at term occurred uneventfully on Dec. 13, 1956.

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Received for publication March 29, 1957.

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She knew she had heart disease, the nature of which was undetermined. There was no history of rheumatic fever. Many years ago, and also in early November of 1956, she was given digitalis because of the appearance of irregular heart action. On both occasions, digitalis had to be stopped immediately because of increased palpitations.

The clinical and roentgenographic findings were consistent with a diagnosis of interatrial septal defect. Systolic and diastolic murmurs were audible in the left upper parasternal region. There was minimal left atrial and left ventricular enlargement, and moderate right atrial and right ventricular enlargement. The pulmonary artery segment was convex and the pulmonary vascular markings were increased.

The electrocardiogram showed an arrhythmia and changes consistent with incomplete right bundle branch block and myocardial disease. Fig. 1 shows Leads I, II, and III taken simultaneously for analysis of the arrhythmia. The electrocardiographic arrhythmia is interpreted as showing reversed reciprocal rhythm and blocked forward conduction of a retrograde-conducted impulse in the presence of sinus rhythm, first and second degree (Wenckebach) heart block with grouping formation.

DISCUSSION

Mines,[5] in 1913, described a curious rhythm occurring in the hearts of the ray and the frog after electric stimulation. This arrhythmia consisted of a sequence of auricular and ventricular contractions due to an impulse which originated in either chamber and which was transmitted back and forth indefinitely from one chamber to the other over the usual conduction pathway. Mines assumed that part of the conduction pathway was refractory during the passage of the impulse in one direction, and was responsive in the opposite direction when the second chamber contracted and while the initially active fibers were refractory.

Drury,[1] in 1924, recognized the similarity between Mines' "reciprocating rhythm" and a type of bigeminy, occurring during atrioventricular rhythm, in which an auricular beat falls near the end of systole of the first ventricular beat of a couplet. Dock[6] credits Wenckebach with the first clinical description of this arrhythmia, based upon a polygram published in 1906. Dock also credits Gallavardin with the first electrocardiographic description, based upon two instances of nodal rhythm due to atropine or ocular pressure, which was published in 1914. The following year, White[7] published a description of a similar arrhythmia. In essence, the electrocardiogram showed a couplet of atrioventricular beats enclosing an inverted P wave, a "sandwich," so White stated, of an auricular contraction between two ventricular beats. In the "sandwich," the P-R interval was shorter than the R-P interval. Drury[1] called this arrhythmia "reciprocal rhythm."

Reciprocal rhythm unlike Mines' reciprocating rhythm is not constant, but consists of a single ventricular response to an auricular beat arising in the atrioventricular node. Furthermore, the atrial beat occurs late in relation to the ventricular beat which originated simultaneously. Partial refractoriness in each direction was postulated to explain both reciprocal and reciprocating rhythm.[1,5]

First degree retrograde block is necessary for reciprocal rhythm, because this delay is regarded as causing the atrial impulse to reach the atrioventricular node outside its refractory period. White showed this well in both his first and second case, by abolishing forward conduction of the retrograde P wave when the

atrioventricular rate was increased.[7,8] Conversely, forward conduction of the retrograde P wave was produced by prolonging the R-P interval with digitalis or vagal stimulation.[9] Ventricular premature beats with retrograde first degree block likewise may give rise to reciprocal rhythm.[10]

The possibility of reciprocal rhythm with an atrial pacemaker was first suggested by Wolferth and McMillan.[11] The basic mechanism in their case was 2:1 heart block. They admitted that their conclusion was questionable, because retrograde conduction was faster than forward conduction. They insisted, however, that because retrograde conduction was present in one of their cases with complete heart block, block less than complete might result in retrograde conduction shorter in time than forward conduction. Katz and Pick's case is questionable (which they admit), because the R-P interval is short and is not followed by a ventricular complex.[4] Lastly, Moe, Preston, and Burlington[3] presented strong experimental evidence for the concept of a dual pathway to explain reciprocal rhythm. They stated that if "serial retrograde impulses," regardless of their original direction, "encroach progressively more upon the relatively refractory period of the node, the time must come when a response can engage only one limb of a dual conducting system, permitting the other to recover in time for the return passage." However, they were not aware of clinical descriptions of reciprocal atrial beats associated with partial block in the normal direction.

In our case, it will be noted that the retrograde P wave appears only after the longer P-R interval. This indicates the importance of the refractory period of the atrioventricular node in the production of retrograde conduction to the atrium. It will be noted likewise that a reciprocal ventricular beat appears only after a preceding shorter R-R interval. This indicates the importance of the refractory period of the ventricle in the production of the reciprocal ventricular beat. The longer the R-R interval, the longer the succeeding refractory period of the ventricle.

The reader may well ask why this arrhythmia is not simply an atrial or nodal premature beat conducted in retrograde direction. Obviously, one does not actually observe the electric current of the P wave in transit. The reason for our interpretation resides in the meaning of electrocardiographic diagnosis. An electrocardiographic diagnosis is a symbol of a logical (verbal) interpretation of an electrocardiogram which is consistent with acceptable physiologic evidence.

The occurrence of a fortuitous premature beat constantly linked to a longer preceding P-R interval is in itself a logical contradiction. Moreover, in the presence of a Wenckebach period, an ectopic beat occurs not at the end of ventricular systole but rather following a prolonged pause. Conversely, a premature beat is almost always followed by an interval longer than the dominant R-R interval. It will be noted that the R-R interval following the reciprocal beat equals that of the dominant R-R interval, because the retrograde P wave apparently terminates at practically the same time that the normal sinus P wave is initiated. The occurrence of the retrograde P wave late in the expected interauricular cycle was emphasized by Wolferth and McMillan,[11] who believe that such timing is necessary to allow for restoration of maximum functional capacity of the junctional tissues. The appearance of the retrograde P wave at

about the same time the sinus P wave is anticipated suggests that the retrograde P wave either blocks the sinus P wave or interferes with its transmission. Lastly, when the heart rate was increased, the relationship between the retrograde and sinus P waves continued to hold. This indicates that the retrograde P wave is constantly linked not only to the preceding, longer P-R interval, but also in time to the sinus rate. Such a constant relationship is likewise inconsistent with the assumption that the retrograde P wave is a fortuitous event. Indeed, when the heart rate was further increased, the P-R interval became constantly prolonged and each alternate ventricular complex was followed by a retrograde P wave. Again, the relationship between the retrograde P wave and the sinus rate was maintained.

In this respect, reversed reciprocal rhythm differs from ordinary reciprocal rhythm. In ordinary reciprocal rhythm, when the atrioventricular rate is increased, the heart rate decreases because the R-P interval is shortened and a reciprocal beat no longer occurs.[7,8] On the other hand, in reversed reciprocal rhythm, an increase in heart rate does not shorten materially the P-R interval. Hence, retrograde conduction with reciprocal beating still occurs. Alternate contractions of the heart so produced and continued constitute reciprocating rhythm.

SUMMARY AND CONCLUSIONS

1. Reversed reciprocal rhythm is described in a case presenting a basic mechanism of sinus rhythm, first and second degree (Wenckebach) heart block.

2. The return of the impulse to the atrium depends upon the refractory period of the atrioventricular node, and a subsequent ventricular contraction upon the refractory period of the ventricle.

3. The diagnosis of reversed reciprocal rhythm is based upon (a) the presence of a retrograde P wave which occurs almost simultaneously with the anticipated sinus P wave; (b) the retrograde P wave arises from a normal-appearing ventricular complex which itself is the result of forward conduction; (c) retrograde conduction time is longer than forward conduction time; and (d) the retrograde P wave gives rise to a ventricular complex identical with that of the dominant rhythm and is followed by a cycle length equal to that of the dominant rhythm.

4. An increase in the rate of the basic mechanism perpetuates reversed reciprocal rhythm but abolishes ordinary reciprocal rhythm.

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ATRIAL FLUTTER WITH 1:1 A-V CONDUCTION CORRECTED BY MITRAL COMMISSUROTOMY

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A CASE of pure mitral stenosis complicated by atrial flutter with paroxysmal 1:1 conduction was observed recently. These paroxysms were uncontrolled by medical means, but promptly disappeared after mitral commissurotomy. The word "uncontrolled" is used to indicate that the paroxysms of 1:1 conduction were not prevented by medical management; we were unable to convert the atrial flutter to a sinus rhythm or auricular fibrillation by medication.

It is a common experience to observe auricular fibrillation or flutter as a complication in mitral stenosis. Drug therapy, however, usually controls the ventricular rate or converts the abnormal rhythm to a sinus rhythm. Although these arrhythmias are undesirable, they are rarely a dramatic complication. Atrial flutter with the presence of 1:1 block, however, constitutes a serious cardiac emergency even in the absence of valvular disease. Since 1:1 atrial flutter was first reported by Lewis[1] in 1915, some 50 additional cases have been described.[2]

CASE REPORT

The patient was a 38-year-old, married, Italian woman who presented herself in July, 1956, complaining of periods of syncope and shortness of breath with exertion. She had felt well until about 6 months prior to this, at which time she began to notice spells of weakness, palpitation, and dyspnea. At first, these episodes occurred only at the time of exertion. During the last month, 3 of these episodes were followed by syncope lasting about 5 minutes each. At the beginning of her illness, she had been hospitalized elsewhere and adequately digitalized. She was maintained on digitoxin until she was first examined by us.

Her past history included a questionable history of rheumatic fever at the age of 12 years. She had a kidney removed in 1947, and cesarean sections in 1949 and 1954. She had known of a heart murmur during her adult life.

Physical examination revealed her weight to be 108 pounds. She was not dyspneic at rest. Her color was good. The cardiac dullness was definitely increased to the left. The cardiac rhythm was regular at 112. The blood pressure was 122/80 mm. Hg. The pulmonic second sound was accentuated. There was a crescendo diastolic murmur ending in an abrupt first sound at the apex. There was a Grade 1 diastolic murmur over the pulmonic area. The liver dullness was 2 fingerbreadths below the costal margin. The peripheral pulsations were good. There was no definite edema of the legs or back. The initial electrocardiogram revealed a ventricular rate of 112, and an auricular rate of 224 (Fig. 1, *A*).

The initial diagnosis was atrial flutter and mitral stenosis. Because of the severity of symptoms, she was hospitalized for further evaluation. She was observed in the hospital for approximately 1 month. During the first 10 days of hospitalization, several attacks of marked, transient tachycardia were observed. An electrocardiogram taken during one of these showed atrial flutter with 1:1 conduction (Fig. 1, *B*). Her digitoxin was then increased to 0.4 mg. a day for 6 days. During this time, her pulse rate was usually about 112, and for short intervals it was found to be 70 to 80. No electrocardiogram was taken at the time of the slow ventricular rate, but it was presumed that this was on the basis of an increased degree of block. However, because of marked nausea and vomiting, administration of the digitoxin was discontinued.

Received for publication April 8, 1957.

After the digitoxin was discontinued, we attempted to convert the auricular flutter to a sinus rhythm or auricular fibrillation by the use of quinidine. However, when the total dose was increased to as much as 1 Gm. in a day, nausea and vomiting occurred, and its further use was considered impractical.

After taking no digitoxin for 7 days, her most prolonged and severe period of tachycardia occurred. She became pulseless during this time and lost consciousness. The tachycardia finally subsided after carotid sinus pressure. She was then re-digitalized with digoxin and observed further. She continued to have incapacitating periods of tachycardia precipitated by the mildest stimulation, such as by a person walking into her room, or by slight exertion.

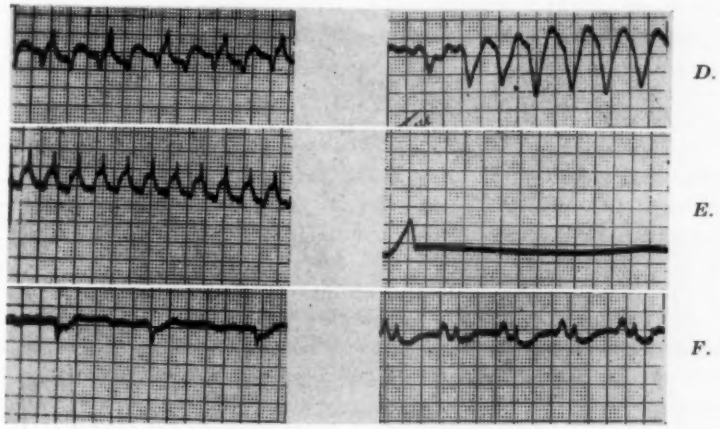

Fig. 1.—*A*, Atrial flutter with 2:1 block. *B*, Atrial flutter with 1:1 conduction, taken during a paroxysm of tachycardia. *C*, Auricular fibrillation just before fracture of the mitral valve. *D*, Ventricular rhythm during fracture of the valve. *E*, Cardiac standstill which occurred soon after ventricular rhythm began. *F*, Sinus rhythm which appeared 12 minutes after commissurotomy.

Because of the gravity of the situation, a mitral commissurotomy was decided upon. This was monitored by a continuous electrocardiogram. Before the operation was started, the rhythm was atrial flutter with 2:1 block. Soon after induction, however, this changed to 1:1 conduction. This persisted for several minutes and again reverted to 2:1 block. Soon after manipulation of the pericardium, auricular fibrillation ensued (Fig. 1, *C*). This persisted until the valve was fractured. At that time, she developed a series of ventricular beats (Fig. 1, *D*) which were soon followed by ventricular standstill (Fig. 1, *E*). During the fracture, a small tear occurred at the base of the auricle; it was controlled by finger tamponade until it could be rapidly repaired and cardiac massage instituted. The periods of asystole lasted up to 12 seconds. After 12 minutes, during which one spontaneous ventricular beat occurred about every 5 seconds, the ventricular rhythm was replaced by a sinus rhythm (Fig. 1, *F*). The sinus rhythm persisted during the closing of the chest, during the postoperative period, and has continued to the present time, 8 months after surgery. No de-fibrillator or pacemaker was used.

She made an uneventful recovery, and daily digoxin, 0.25 mg., was continued. She is completely rehabilitated and now takes care of her home and children without experiencing-symptoms.

SUMMARY

A case of persistent atrial flutter with periodic 1:1 conduction complicating mitral stenosis converted to a sinus rhythm 12 minutes after mitral commissurotomy.

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Book Review

CARDIOPATHIES CONGÉNITALES. By Pierre Soulié, Ed. 2, Paris, 1956, L'Expansion Scientifique Française.

The second edition of Professor Pierre Soulié's book on congenital heart disease is a 430-page text with 307 illustrations. Assisted by 27 co-authors, Professor Soulié has maintained the outline of his first edition but revised each chapter with special attention to recent developments in this field and the rapid progress of cardiac surgery. This remarkable text is of great assistance to all cardiologists and especially those interested in congenital heart disease. Any physician who follows the progress of modern cardiology will appreciate reading it.

To the cardiologist, this book is a precise synthesis of all the problems encountered in congenital heart disease. For each disease entity, the author reviews the anatomy, clinical and x-ray findings, electrocardiography, differential diagnosis and finally the treatment, taking into account the actual possibilities of cardiac surgery.

To the physician, this book reads easily. In the first part, the author presents the basic data necessary to the understanding of congenital heart diseases (embryology, cyanosis, etc.) and the diagnostic methods in use (cardiac catheterization, angiocardiography, electrocardiography, and vectorcardiography). In the second part, the different types of cardiopathies are discussed in detail. In the third part of the book the author reviews mainly the different aspects of surgery (anesthesia, surgical techniques, and electrocardiography during surgery).

The general construction of Professor Soulié's book was planned with great care and the diagrams and pictures are excellent. The text is concise and illustrated with a large number of well-chosen documents. The author and his collaborators express their personal opinions on each of the subjects discussed. One cannot help but be impressed by the wide range of material gathered, and the author's opinion appears to be based on a careful study of a large number of patients.

The book is primarily an expression of the author's views on the subject. Nevertheless, foreign contributions are given proper credit. Although a typically French book, the reader gets the impression that the field of congenital heart diseases has advanced through the joint efforts of many nations. The American contribution is particularly stressed.

Professor Soulié deserves our admiration and should be congratulated for a book which must be considered as a basic text in the field of congenital heart disease. The simplicity of the language used makes it easy for the American reader to understand. Any criticism which might be advanced must indeed be a very minor one, and, in any case, would be far outweighed by the book's usefulness.

In summary, it is an excellent book, written by experienced cardiologists, under the supervision of a remarkable chief. It covers two decades of rapid progress in the field of medicine.

P. D.

Announcements

A COURSE IN INTERPRETATION OF COMPLEX ARRHYTHMIAS will be given at Michael Reese Hospital by Louis N. Katz, M.D., Richard Langendorf, M.D., and Alfred Pick, M.D. This is an advanced course intended only for experienced electrocardiographers. The class will meet daily from 9:00 A.M. to 5:00. P.M., Dec. 9 to 13, 1957.

Further information and a copy of the lecture schedule may be obtained from the Secretary, Cardiovascular Department, Medical Research Institute, Michael Reese Hospital, Chicago 16, Ill.

The ALBERT EINSTEIN MEDICAL CENTER will conduct a POST-GRADUATE COURSE IN BASIC ELECTROCARDIOGRAPHY at the Southern Division, Fifth and Reed Sts., Philadelphia 47, Pa., beginning Nov. 6, 1957. The course will consist of a total of 36 hours of instruction divided into 12 sessions of 3 hours each. The sessions will be held on consecutive Wednesdays from 2 to 5 P.M. The fee for the course is $50. Registration closes on Oct. 27, 1957.